INTERACTION BETWEEN THE WATERHYACINTH MITE,
Orthogalumna terebrantis WALLWORK,
AND THE MOTTLED WATERHYACINTH WEEVIL,
Neochetina eichhorniae WARNER

By

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DEDICATION

I proudly dedicate this dissertation to my late father, né Francis Edouard Delfosse, and to my wife, Janet Ann Veronica Del Fosse.

E.S.D.F

December 1975

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By

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December, 1975

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Major Department: Entomology and Nematology

Seven hundred adult mottled waterhyacinth weevils (*Neochetina eichhorniae* Warner) were released on a waterhyacinth (*Eichhornia crassipes* (Mart.) Solms-Laubach) mat infested with waterhyacinth mites (*Orthogalumna terebrantis* Wallwork). Plants averaged significantly ($P= 0.05$) smaller after 50 weeks. Average petiole length was reduced by over 30 cm after 4 generations of adult weevils had emerged. Density of plants was reduced from an average of 34 plants/m^2 at the time of weevil release to an average of 26 plants/m^2 after 50 weeks. Weevil populations increased geometrically and reduction in plant size and density was closely correlated with weevil population increase.

Mite populations fluctuated with weather. Temperature and humidity were the abiotic factors most influential in affecting mite population development. Waterhyacinth mites apparently move to pickerelweed (Pontederia cordata L.) under conditions of low temperatures and high humidity, and move back to waterhyacinth under higher temperatures and humidity. Mites laid more eggs and immature mites developed to adults best at 15-35°C. In the field, waterhyacinth mite damage is associated with fungal pathogens and saprophytes. Weevil feeding spots, which had formerly been thought to be associated with these pathogens and saprophytes, in fact were not seen to be conducive to their development. The fungus Acremonium zonatum (Saw.) Gams. developed on waterhyacinth only after adult waterhyacinth mites had created their emergence holes in the pseudo-laminae.

Adult waterhyacinth mites did not adversely affect the population buildup of mottled waterhyacinth weevils. Weevils actually oviposited more ($P=0.05$) eggs when waterhyacinth mites were present than when they were absent. This may be due to the presence of a "kairomone" in waterhyacinth tissue that is released from plants that are damaged by arthropod feeding or structural breaks.

Adult waterhyacinth mites will starve in the presence of weevil eggs as their only source of food. Weevils and mites in combination tended to act synergistically in their damage on waterhyacinth, while reducing plant size and abundance, and opening plants to attack from pathogens and saprophytes.

INTRODUCTION

In North America more than 170 aquatic plants are classed as weeds, with 40-50 causing major problems (Timmons 1970, Weed Science Society of America 1971). Holloway (1964) considered submersed aquatics to be the most serious because they can reduce water flow and cause recreational problems. Sculthorpe (1967), however, considered the stoloniferous free-floating plants, such as waterhyacinth (Eichhornia crassipes (Mart.) Solms-Laubach),[1] to be the most serious of the problems.

Biological control, despite the claim by some that it ". . . has become a household term." (Bendixen 1974) is still greatly misunderstood by lay people. Even though weed science (matology) and weed control (matonomy) have developed greatly in recent years (Camargo 1974), there is still much hesitation involved by lay people whenever biological control is considered. This concern is caused mainly by misunderstanding; lay people often confuse biological control with biological or biochemical warfare or point to introductions of exotic plants (e.g. Hydrilla verticillata Rolle)[2] or fish (e.g. Tilapia spp.)[3] as reasons not to use biological

[1]Farinosae: Pontederiaceae.

[2]Helobiae: Hydrocharitaceae.

[3]Perciformes: Cichlidae.

control. However, no biological control of weeds program carried out by responsible scientists has ever resulted in a deleterious introduction.

Examples of entomophagous control of introduced terrestrial plants are numerous (Dodd 1940, Huffaker and Kennett 1959, Holloway 1964), but only 1 aquatic plant, alligatorweed (Alternanthera philoxeroides (Mart.) Griseb.),[4] has been controlled biologically to date (Brown and Spencer 1973).

In order to appreciate fully the need for biological control of waterhyacinth, one only needs to review the record compiled by other methods of control. Chemical, mechanical or cultural control methods are highly inefficacious, on a practical scale. These methods have proven successful only briefly and over restricted areas. In 1947, 63,000 acres were covered by waterhyacinth in Florida (Perkins 1972). From January 1960-June 1962, 55,000 of the 70,000 acres of waterhyacinth were treated with chemicals, but in 1962, over 80,000 acres were covered with waterhyacinth (Tabita and Woods 1962). In 1972, Dr. A. Burkhalter of the Department of Natural Resources of the State of Florida estimated that over 200,000 acres were covered with waterhyacinth in Florida, even though 70-100 State, Federal, City and County agencies now use chemicals for control of waterhyacinth (Perkins 1972). Dr. C. B.

[4]Centrospermae: Aramanthaceae.

Bryant, in response to my questioning at the recent Hyacinth Control Society Annual Meeting in San Antonio, Texas, said that the effective depth of mechanical control was only 5 feet, although the machinery could be modified, with a great deal of trouble, to operate at 7-8 feet. Such equipment may have limited use in control of waterhyacinth under certain conditions of easy accessibility. Its use in severely limited in control of submersed aquatics for it does not remove roots, turions, stolons, etc., and may stimulate new growth as old growth is removed. Present cultural methods are simply not practical over large expanses of waterhyacinth infestations. Biological control may be the least expensive, most practical, most effective and most ecologically acceptable method that can be used against waterhyacinth. Integrating biological control with other methods may also have application (Entomological Society of America 1975).

If biological control of waterhyacinth is to be evaluated, we must have techniques available that will enable us to follow closely populations of all agents involved. Since all presently used biological control agents of waterhyacinth are exotic, it will be necessary to see how the agents affect each other, as well as populations of waterhyacinth and naturally occurring arthropods that utilize waterhyacinth mats.

The first biological control agent of waterhyacinth released and established in Florida was the mottled waterhyacinth weevil, Neochetina eichhorniae Warner.[5] The waterhyacinth mite, Orthogalumna

[5]Coleoptera: Curculionidae.

terebrantis Wallwork,[6] was probably accidentally introduced in 1884 with the first waterhyacinth plants. It was first found in the United States in 1968 (Bennett 1968b). This study was initiated to determine the effects of these arthropods on each other as well as on waterhyacinth.

To fully and accurately assess the effects of these biological control agents as compared to other methods used, it is imperative that these other techniques be understood. Consequently I have reviewed below other commonly used control methods and agents of waterhyacinth.

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[6]Acari: Galumnidae.

LITERATURE REVIEW

The Problem

World-Wide Infestation

Little (1965) found that waterhyacinth grows profusely in Asia, Australia, New Zealand, South America and Pacific Islands, and is still spreading (Soulthorpe 1967). Ingersall (1964) found waterhyacinth to be a major problem in Africa, Australia, India, Ceylon and Java, while Holm et al. (1969) and Little (1965) considered it to be circumglobal and one of the world's major weeds. Matthews (1971) commented that it is illegal to possess waterhyacinth in New Zealand— the only such restriction on any plant there. Waterhyacinth is also a problem in the Panama Canal (Hearne 1966), Australia (Bill 1969, Kleinschmidt 1974, Springell and Blake 1975), India (Jain 1975, Sahai and Sinha 1969), Southeast Asia (Soerjani et al. 1975), Sudan (Gay and Berry 1959, Mohamed 1975), the Makon River (Gangstad et al. 1972, Anonymous 1974), Puerto Rico (Rushing 1974), Pakistan (Naik 1972), and the United States (Perkins 1972, 1973a, b, 1974, Bock 1969, Johnson 1920).

The area of origin of waterhyacinth is South America (Klorer 1909, Wunderlich 196 , Webre 1975). Bock (1969, 1972) found that the

natural distribution of waterhyacinth was due to its morphological characteristics and wide range of environmental tolerances.

Florida's first waterhyacinth was reportedly placed in the St. Johns River in about 1885 by Mrs. N. F. Fuller, at San Mateo, 5 miles south of Palatka (Tilghman 1962). These plants may have originated in Venezuela (Webre 1975), and were shown at the Cotton States Centennial Exposition in New Orleans, Louisiana, in 1884 (Wunderlich 1967, Klorer 1909). By 1890 waterhyacinth was established in Florida (Webber 1897). In addition to the several State, Federal and City control operations against waterhyacinth, in 1961 the Governor of Florida established the Lee County Hyacinth Control District (Miller 1964).

Waterhyacinth was first officially recognized as a serious hydrophyte on 4 June 1897 with the passage of a Congressional Act authorizing the Secretary of War to investigate the effect of waterhyacinth on obstructing navigation in Louisiana and Florida waters (Penfound and Earle 1948).

Specific Problems Caused by Waterhyacinth

Problems caused by infestations of waterhyacinth are varied. Several authors have commented on the mosquito breeding sites created by waterhyacinth (Berber and Haynes 1925, Mulrenan 1962, Sealbrook 1962, McDonald and Lu 1973). Ingersall (1964) found that thick mats of waterhyacinth prevent small fish from feeding on mosquito larvae. Wilson (1967) stated that without aquatic plants many

of our mosquito problems cannot exist.

Basic to the problems caused by waterhyacinth is its phenomenal growth potential (Das 1956, Westlake 1963, Yount 1964, Sheffield 1967, Knipling et al. 1970, Rogers and Davis 1972.) The presence and abundance of a weed in a particular area depends upon the area's history and the weed's ability to reproduce with existing climatic, edaphic, hydrologic and biotic limitations, disturbance of habitat, etc. (Andres 1973). Spencer (1974) reported that the dry weight production of waterhyacinth, less roots, was 11,880 kg/ha for 3 months (compared to Byer and Sturrock's (1965) estimate of 13,338 kg/ha for whole plant production of maize.) Davis (1970) reported that waterhyacinth could double in volume every 12.5 days during the growing season. Thus, considering the average growing season in northeast Florida to be 300 days (Laessle 1942), 1 acre of waterhyacinth under optimum conditions would theoretically cover in one year more than 12 million acres of water with plants of equal density. Penfound and Earle (1948) found that 1 plant could produce 2000 daughter plants in 3 months and 10 plants produced 655,360 plants (1 acre) in 8 months under good growing conditions. A single plant reproducing vegetatively covered 7000 yards^2 in 1 month (Vaas 1951). Spafford (1935), Das (1969) and Anonymous (1970) also commented on the rapid proliferation of waterhyacinth. Wahlquist (1972) found production of waterhyacinth to be highest in ponds fertilized with N-P-K fertilizer in a combination of 8-8-0. Bonetto (1971) noted that waterhyacinth upset the ecological balance

of waters by interfering with native hydrophytes and fish. Standing crop of waterhyacinth varied from 0.72 kg/m^2 (Sahai and Sinha 1969) to 1.4 (Dymond 1949) to 1.5 (Penfound and Earle 1948) on a dry weight basis.

Many other estimates of waterhyacinth growth are available, but one must keep in sight the reasons why waterhyacinth can proliferate so greatly. Certain prerequisites are needed. Waterhyacinth requires "a great intensity of light" (Druijff 1974). A pH of less than 4 is toxic to waterhyacinth (Druijff 1973) and 7 is optimal for growth. Our streams, lakes and canals are nutrient baths; Kemp (1968) commented that streams in densely populated areas carry 6000 pounds of P/mile, and P in domestic sewage is equal to 3 pounds/person/year (Makenthun 1969). Low temperatures can limit waterhyacinth growth. The purplish-white roots of waterhyacinth (Olive 1894) will be killed by water temperatures below 28°F (-2.2°C) (Backman & Co. 1930).

Waterhyacinth doesn't produce seeds in all areas of its distribution (Bock 1966, Druijff 1973), but seeds can be very important to the widespread distribution of waterhyacinth. When flowers are present, basal and capital bending of the petiole thrusts the inflorescence into the water, where seeds are released (Rao 1920). In New Zealand each flower on the spike has been able to produce more than 300 seeds, and with 20 or more flowers/spike, each plant can produce 5000 seeds (Matthews 1971). Coupled with a seed viability found in New Zealand of more than 20 years, one can

see why the efficacy of short-term control methods is poor. Matthews (1967) found that seeds can withstand submersion or desiccation for 15 years, and experiments at the University of Khartoum (Chadwick and Obeid 1966) determined that sandy soil stops seed germination. In mud, waterhyacinth seeds are viable for at least 7 years (Parya 1934, Hitchcock et al. 1949). Scarification is needed for seed germination, not light _per se_ (Parija 1934). Waterhyacinth does produce seeds in Florida, but the major method of reproduction there, as most places, is vegetative. Waterhyacinth will root on muddy banks, and can survive even when the water level drops (Spruce 1908).

Waterhyacinth is also detrimental as a factor causing water loss through evapotranspiration (Linacre et al. 1970, Perkins 1972, Anonymous 1962, Brezny et al. 1973). In fact, only American Pondweed, _Potamogeton_ _nodosus_ Poir,[1] has a higher recorded evapotranspiration rate than waterhyacinth (Otis 1914). Timmer and Weldon (1967) found that the average waterhyacinth evapotranspiration rate was 3.96 inches (10.8 cm) of water/week, while pan evaporation was 1.08 inches (2.75 cm)/week; i.e. evapotranspiration was 3.7 times evaporation. More than 6 acre-feet of water could be lost in this manner in 6 months. Other estimates of evapotranspiration rates of waterhyacinth include values from 1.48 (Van Der Weert and Kamberling 1974) to 3.2 (Penfound and Earle 1948) to 5.3 (Rogers and Davis 1972) to 7.8 times

[1]Helobiae: Potamogetonaceae.

evaporation (Anonymous 1972d). Such results caused Timmer and Weldon (1967) to state "more water can be lost through evapotranspiration from waterhyacinth on large reservoirs, water conservation areas, and irrigation canals than is supplied for storage purposes." They also felt that efficient use of water could be impossible where waterhyacinth reduces water flow 50% or more, as can occur (Stephens et al. 1963) or causes water loss through evapotranspiration. Factors that influence evapotranspiration are humidity and wind (Meyer and Anderson 1955), and diurnal fluctuation in water temperature is largely due to incident solar radiation (Anonymous 1967). Since water for irrigation may cost from $1-20/ acre (Frevert et al. 1955, Houk 1956), a considerable monetary loss is also involved.

Other problems are also caused by waterhyacinth. The oxygen-depleting pollution and load imposed by 1 acre of waterhyacinth is equal to the sewage created by 40 people (Ingersall 1964). Dissolved carbon dioxide (DCO_2) uptake is an important aspect of waterhyacinth ecology (Ultsch 1973). Ultsch (1974) found that dissolved oxygen (DO), pH and temperature were lower under a mat of waterhyacinth, and DCO_2 was higher when compared to areas containing only submerged macrophytes. Lynch et al. (1947) found that when the water chemistry of an open water situation is compared to that under waterhyacinth, surface water under waterhyacinth is more uniform, acidity and DCO_2 are higher, and DO is lower. Few fish can tolerate such conditions.

Waterhyacinth obstructs navigation and other uses of water (Zeiger 1962, Perkins 1972, 1973a), reduces real estate values (Ultsch 1974), and increases turbidity and pollution of water (Timmer and Weldon 1967). Large monetary losses result from large-area infestations of waterhyacinth (Heinen and Ahmed 1964, Wild 1961, Anonymous 1957, 1970-'71).

Free-floating rafts of waterhyacinth destroy valuable submerged plants (Perkins 1973a, 1974) and concentrates American coots, _Fulica americana_ L.,[2] in ponds where migratory waterfowl usually live. Coots then eat all available duck food (Gowanlock 1944). Aviators have mistaken waterhyacinth rafts for landing strips (Johnson 1920). Mats of waterhyacinth cause sewage to back up in some areas (Penfound and Earle 1948) and accelerate fresh water succession (Russell 1942). Waterhyacinth, in blocking canals, also interferes with fishing and other recreational sports and hinders water transportation (Perkins 1974). For these and other reasons, Holcomb and Wegener (1971) considered only waterhyacinth, out of 89 aquatic plants near Kissimmee, Florida, to be detrimental "to the fishery and other plant communities."

In summary, reasons to control waterhyacinth include:

(1) interference with navigation;

(2) clogging of water drains, irrigation canals, spray equipment and pumps;

(3) causing unsightly appearances by completely covering the

[2] Gruiformes: Rallidae.

water surface;

(4) interference with fishing, swimming and other aquatic recreational sports (Anonymous 1970);

(5) reduction of open water available for waterfowl, and decreases waterfowl hunting;

(6) creation of ideal breeding grounds for mosquitoes and other aquatic insects which utilize protected water found in and around plants;

(7) reduction of fish populations by competition for water space and basic nutrients (food elements) in the water, which may result in an over-abundance of small, undesirable fish; and

(8) direct economic loss due to evapotranspiration and creation of deep beds of organic matter on stream and lake bottoms.

Benefits of Waterhyacinth

Not all aspects of waterhyacinth ecology are negative. Positive aspects of waterhyacinth include:

(1) removal of nutrients from water;

(2) useage as raw material for production of natural gas and fertilizer (contains Cd, Ni, Pb, Hg, Au, Ag, NO_3 and PO_4);

(3) production of products such as planting pots;

(4) useage as a mulch and soil additive;

(5) useage as beautification tool;

(6) production of animal food; and

(7) experimentally used for paper production, packing material,

etc.

Waterhyacinth can remove N and P from sewage (Sheffield 1967, Yount and Crossman 1970, Ramachandran et al. 1971, Boyd 1970, Anonymous 1971, Scarsbrook and Davis 1971, Haller and Sutton 1973). Rogers and Davis (1972) found that 1 ha of waterhyacinth under optimum growing conditions could absorb the daily N and P waste of over 800 people, while 1 ha of waterhyacinth could remove the annual N waste production of 500 people and P of 225 persons (Boyd 1970). This is especially important when one considers that P is one of the most ecologically important elements, and a deficiency of P, therefore, may limit productivity (Hutchinson 1957). Waterhyacinth also removes copper sulphate pentahydrate (Sutton and Blackburn 1971) and Ramachandran et al. (1971) found that 1 acre of waterhyacinth could remove 3,075 pounds of N/year and had a protein content almost equal to that of milk.

One acre of waterhyacinth produced $2000 worth of low grade methane gas/year (1 million ft^3) by anaerobic fermentation in a pilot study, with the residue used as a high-grade fertilizer (Webre 1975). Waterhyacinth has also been suggested as a source of potash (Day 1918).

Waterhyacinth has very high nutrient removal capabilities (Rogers and Davis 1972, Sheffield 1967, Steward 1969, Knipling et al. 1970). Scarsbrook and Davis (1971) found that waterhyacinth could absorb 2.87 g P, 6.93 g N and 8.73 g K in 23 weeks. Ornes and Sutton (1975) found a maximum of 5,500 mg P/g dry weight (DW)

occurred when the level of P in sewage effluent (in which plants were grown) was 1.1 mg/ml, and found that plants produced 1.9 daughter plants/week, as did Rushing (1974). Dunigan et al. (1975) found waterhyacinth removed NH_4^+-N in the field and greenhouse and NO_3^--P in greenhouse tests, and Silver et al. (1974) showed that waterhyacinth roots could anaerobically fix N_2. Rao et al. (1973) found that waterhyacinth took up Fl to the extent of 75 mg. Waterhyacinth doesn't absorb orthophasphate in proportion to the amount in water (Knipling et al. 1970), and less than 0.10 ppm is lethal to waterhyacinth (Haller et al. 1971). Excessive amounts of P absorbed by waterhyacinth are not associated with an increase in yield (Gerloff 1969, Gerloff and Krumbholtz 1966).

Waterhyacinth is used as food for cattle (Davies 1959), buffalo (Anonymous 1951) and pigs (Grist 1965, Anonymous 1952) in India, and for cattle and pigs in Madagascar (Anonymous 1965). It has also been used for silage in the Philippines (Agrupis 1953) and elsewhere (Bagnall et al. 1974, Byron et al. 1975); for yeast production in Brazil (Oyakawa et al. 1965); for composts and mulch for tea in India (Basak 1948, Anonymous 1966); as a source of protein (Pirie 1960, 1970, Boyd 1968a, b, Krupauer 1971) containing useful growth substances (Sircar and Ray 1961, Sircar and Chakraverty 1961, Sircar and Kundu 1960, Mukherjee et al. 1964, Bhanja and Sircar 1966, Bhanja et al. 1968, Iswaran and Sen 1973, Maiti 1974, Parra and Hortenstine 1974, Sircar et al. 1973) and gibberellins (Sircar and Chakraverty 1962); to enhance growth of microorganisms and plants and accelerate

alcoholic fermentation (Sheikh et al. 1964); for fodder in South Central China (Naik 1972); for cows, horses and pigs in North America (Vaas 1951); for manure (Smith and Thornton 1945, Singh 1962); and as a source of lysine and other amino acids as a supplement to grain protein (Taylor and Robbins 1968). Liang and Lovell (1971) found that waterhyacinth could be a good substitute for alfalfa meal in catfish diets, while it is also used (Anonymous 1974) for fish and animal food, and for paper. Several other authors have suggested using waterhyacinth as animal food (Baldwin et al. 1974, Little 1968a, Boyd 1968a, 1969, Combs 1970, Salveson 1971, Stephens 1972, Bagnall et al. 1973, Hentges et al. 1975). Little (1968a) and Boyd (1968a) emphasized food resources that could possibly be developed from native macrophytes, and Boyd (1971a) compiled a bibliography of utilization of aquatic plants, while Naik (1972) reviewed waterhyacinth use in West Pakistan. In short, waterhyacinth only needs to be harvested to be useful, "if a use can be found" (Pirie 1960).

Waterhyacinth also reduces bank erosion by damping wave action (Tilghman 1962, 1964, Maltby 1963) and has value as a mulch (Tilghman 1962).

Nolan and Kirmse (1974) and Vaas (1951) found waterhyacinth unsuitable for paper making because of low pulp yields and drainage rates.

Finally, waterhyacinth is one of the best biotic salinity indicators (Penfound and Hathaway 1938).

Even though waterhyacinth has many potential uses and benefits, on a practical basis, no use has been developed, or benefit derived, that counterbalances the detrimental aspects of waterhyacinth biology.

Monetary Relationships

Holm et al. (1969) estimated that aquatic ditchbank weeds cause an annual loss of 1,272,480 acre-feet of water, costing \$39¼ million in 17 western states. Annual damage from waterhyacinth alone in Louisiana in 1947 was \$1-15 million, with \$5 million/year a conservative estimate (Lynch et al. 1947). Other estimates on losses due to aquatic weeds are also high.

Although millions of dollars are spent yearly on the highly inefficaceous methods of chemical and mechanical control of waterhyacinth, only \$380,000 was spent during the first ELEVEN YEARS (through fiscal year 1973) on ALL ASPECTS of biological control of waterhyacinth.[3, 4] By comparison, savings by biological control of Klamath weed, Hypericum perforatum L.,[5] which now costs nothing

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[3]Coulson, J. R. 1972. Potential environmental effects of the introduction of the Argentine weevil, Neochetina eichhorniae, into the United States. Tech. Rept. Interag. Res. Adv. Comm. Meet., Aq. Plant Contr. Sec., US Army Corps of Engin., Houston, TX, 19 p.

[4]Due to restrictions placed on USDA and similar reports, this, and subsequent reports, are footnoted and not listed in "Literature Cited".

[5]Parietales: Hypericaceae.

to control, exceed $2 million/year.[3]

Conflict of Interest

The use of phytophagous organisms is limited because of their small size, high reproductive rate and high mobility. Thus, introduced natural enemies in one area of an undesirable plant's distribution may spread into other areas where the plant is desirable (Andres 1973). Several examples of this are available. The introduced phreatophyte salt cedar, *Tamarix pentandra* Pall.,[6] is a problem at certain times of the year in Arizona, New Mexico and Texas where it impedes water flow, causes flooding, and transpires great amounts of water in the dry season. However, it also provides nesting areas for white winged dove, *Zenaida asiatica* L.,[7] nectar and shelter. If the weed were reduced to lower abundance (i.e. leaving enough plants to support doves, etc., yet reducing abundance to a tolerable level for other interests), the conflict of interest might be resolved (Andres 1973). Ensminger (1973) stated that alligatorweed, *Alternanthera phileroxeroides* (Mart.) Griseb.,[8] is an important food for wildlife in Louisiana coastal marshes, and also protects stream banks from erosion, and that the

[6]Parietales: Tamaricaceae.

[7]Columbiformes: Columbidae.

[8]Centrospermae: Aramanthaceae.

alligatorweed flea beetle, Agasicles hygrophila Selman,[9] has already damaged plants in marsh areas grazed by cattle.

Yellowstar thistle, Centaurea solstitialis L.,[10] is exotic and causes economic loss in grazing ranges and grain and seed crops in California. It is also important for bees, Apis mellifera L.[11] which pollinate fruit and seed crops in California. Since the cattle industry was the predominate direct interest, biological control has been started (Andres 1973). Results are as yet inconclusive.

There has never been any question of conflict of interest with control of waterhyacinth,[3] but if economic uses are found, one may develop.

Control Attempts Other Than Biological Control

Chemical Control

> The best thing that can be said for spraying chemical poisons on lakes in the grip of algae and weeds is that it is usually a futile undertaking. Treating a lake with copper sulphate or other toxic chemicals is no more effective than taking aspirin for a brain tumour. It offers only a temporary relief, maksing symptoms of cultural eutrophication. In the long run it makes a lake sicker. Poisoning algae and weeds simply accelerates the natural process of growth, death and decay, thereby freeing nutrients for another cycle of plant production (Hasler 1968).

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[9]Coleoptera: Chrysomelidae.

[10]Tubiflorae: Cynareae.

[11]Hymenoptera: Apidae.

The above statement is typical of the environmental uproar over the indiscriminate use of poisons on our lakes, streams, canals and terrestrial areas. In the past, most lay people were convinced that chemicals may be the answer to all their pest problems. But, as Hasler (1972) stated

> As I observe the public clamouring for chemical treatment of a lake or stream to rid it of carp [*Cyprinus carpio* L.],[12] watermilfoil (*Myriophyllum* spp.)[13] or water hyacinth (*Eichhornia crassipes*), I search in vain for the basis of this faith in chemical magic. Have we professionals been sold on the chemical 'fix' and passed it on innocently to the public in conservation bulletins and public meetings.

And "attempts to control [waterhyacinth and other aquatics] has presented Florida citizens with a multimillion dollar expense and created a bonanza for the [chemical industry] " (Anonymous 1972d).

Aquatic herbicides are used very extensively in the world, however, and apparently with some success. One of the most widely used herbicides on waterhyacinth is 2,4-D.[14] Amine formulations of 2,4-D at 3.5-4.5 kg/ha reportedly gives good waterhyacinth control if at least 80% of the leaves are covered (Druijff 1973). Timmer and Weldon (1967) and Anonymous (1967) found that 2,4-D reduced water loss through evapotranspiration. Sen (1957) controlled waterhyacinth with a 2% concentration of 2,4-D without any apparent

[12] Cypriniformes: Cyprinidae.

[13] Myrtiflorae: Haloragaceae.

[14] (2,4-Dichlorophenoxy)acetic acid.

effects on aquatic fauna.

Many other people have studied or recommended use of 2,4-D and other chemicals on waterhyacinth (Anonymous 1960, 1970, 1972c, Klingman 1961, Baruah et al. 1955, Lawrence 1962, Gallagher 1962, White 1962, 1964, Blackburn and Weldon 1963, Weldon et al. 1966, Zeiger 1963, Rogers and Doty 1966, Braddock 1966, Phillippy 1966, Little 1968b, Wentzel 1968, Misra and Das 1969, Achuff and Zeiger 1969, Blackburn et al. 1971, Patro and Tosh 1971, Dynansagar and Dharurkar 1972, 1974, Moody 1973, Pieterse and Van Rijn 1974).

One of the greatest disadvantages, other than cost, of using chemicals for control of aquatic weeds is the potential side effects on non-target organisms and other adverse environmental effects. Druijff (1973) found that drift, reduction in DO due to decomposition, and accumulation of organic debris raising the level of the lakebed are all problems that should be considered in applying chemicals. Shoecraft (1971) wrote on the growing concern of the effects of 2,4-D on non-target organisms, and recent studies showed that 2,4-D caused teratogenic effects of game birds (Lutz-Ostertag and Lutz 1970). Mauriello (1970) found that use of 2,4-D causes undesirable recycling of nutrients into already over-nutrified waters by setting up large biochemical demands. Paulson (1970) found that there was "a real hazard to bees and possibly other nectar-feeding insects from application of 2,4-D to plants in flower." Tilghman (1963) protested the use of chemicals (as they are now applied) more than 10 years ago, and reported that cattle were killed after eating

sprayed waterhyacinth along the St. Johns River (1), so spraying was stopped. Montelaro (1962) pointed out problems in using herbicides, especially effects of 2,4-D on non-target organisms. Hamilton (1966) said that damage by 2,4-D is widespread and at a very high level, and Finny (1962) stated "it is possible for whole towns to be defoliated by [2,4-D and other] herbicides carried in the water supply if care is not exercised to keep them out of that supply." Foul odors and tastes in water can also result from 2,4-D (Faust and Aly 1962). Vaas (1951) however, found no harmful effects to fish or other biota if 2,4-D is used properly.

Druijff (1974) summed up the chemical control story adequately by stating

> in places where machines cannot operate and where chemicals represent the only alternative to the costly process of weed removal 'by hand', chemicals have their uses, but must be applied with great discretion.

Mechanical, Cultural and Integrated Control

Mechanical removal has been used for years as a method of "controlling" aquatic macrophytes. Bryant (1973) pointed out that though little work has been done on the long-term effects of mechanical harvesting of aquatic weeds, there is "little or nothing to indicate that it is harmful." Ahmed (1954) and Chokder and Begum (1965) reported that removal by hand is used in East Pakistan, whereas Asim (1961) and Siddiqi (1962) suggested both hand removal and use of 2,4-D in West Pakistan. Naik (1972) found that 1 person

could remove 500 plants/hour which ". . . is useful and effective but requires large numbers of personnel for the complete eradication of waterhyacinth"— but recommended hand-removal. Livermore and Wunderlich (1969) and Nichols and Cottam (1972) commented on existing harvesting equipment for waterhyacinth. Sawboats were used with success in Louisiana, but left a fringe of plants that quickly grew back (Wunderlich 1962). Wunderlich (1938) found that physically crushing plants killed them very well. Finally, Wunderlich (1967) said ". . . a well-planned combined mechanical-chemical approach is the most satisfactory method of keeping our waterways open at a reasonable cost."

Mohamed and Bebour (1973a, b) found that burning and back-burning controlled waterhyacinth. Richardson (1975) found that a combination of drawdown, drying and freezing could be effective for waterhyacinth control in Louisiana, while Hestand and Carter (1974, 1975) found that drawdown actually increased the amount of waterhyacinth present.

Coudi et al. (1971) discovered that N_2CO_2-He laser energy on waterhyacinth resulted in immediate, visible plasmolysis, then a burning (proportional to the amounts of laser energy applied), then an endogenous systemic response (at high rates). They also discovered that physiological age was important in utilization of the laser system. Couch and Gangstad (1974) found that laser energy (10.6 nm) at levels of less than 1 J/cm^2 for individually-irradiated plants, and 69 J/cm^2 for group-irradiated plants significantly

reduced waterhyacinth growth, and at a level of 4 J/cm^2 reduced photosynthesis 50%. No practical field use has been found for lasers in waterhyacinth control, however.

Inundation has also been tried as a method of suppressing waterhyacinth growth, without success. An abscission zone is formed across the rhizome of a bulbous petiole, and plants float to the surface in 20-40 days (Robertson and Thien 1932).

Integrated control of waterhyacinth using 2,4-D and insects in various combinations has been investigated very little to date. Preliminary results, however, have been encouraging (Perkins, pers. comm.).

Biological Control

General Theory of Biological Control of Hydrophytes

> Aquatic plants are part of a healthy aquatic ecosystem. The aim of management should be, therefore, to control aquatic plants by restoring them to their original balance or some anthropocentrically-determined allowable balance, in the case of exotics ; it should not be to eradicate them (Nichols and Cottam 1972).

This statement represents the view of biological control advocates, and is the most ecologically-sound concept of control. One way, and perhaps the only way, that management can be achieved is through the use of biological control agents.

Not all people favor using biological control agents, however.

As Paulson (1970) has written

> A common fallacy of both chemical and biological control is that they tend to ignore the basic cause of our aquatic weed problem, which is water pollution. Any attempt to control aquatic weeds which does not also remove excess nutrients from the water is doomed to failure. Such methods invite reinfestation by the same weeds, or an invasion by other species which may be even more objectionable.—Until we discontinue the practice of using our waterways as open sewers, . . . , aquatic weed control is an exercise in futility. Under present conditions, and as far as can be seen into the future, we expect a bumper crop of aquatic weeds to invade our waters every summer. The time is long past due to approach the problem from the standpoint that aquatic weeds represent a useful crop to be utilized and harvested.

Apparently insignificant insects can tip the balance in favor of a competing plant species; a principle in effect in South America, where other macrophytes gain some surface area in relation to waterhyacinth when waterhyacinth is attacked heavily (Huffaker 1964). This is true despite White-Stevens' (1975) contention that, for the practical grower, biological control is ". . . too specific, too late, too ephemeral, too unreliable, too complicated, too impractical and too costly" (!) to be used efficiently. He also stated that

> There is not one commercial crop or livestock animal which can be economically produced to meet current federal and state standards of quality and be completely protected by biological methods of pest control.

The aim of biological control of weeds is to reduce weed abundance by introducing natural enemies, or augmenting their action. It can be successful, depending upon the number of weed species involved, phylogenetic proximity of beneficial plant species, type and stability of habitat, and degree and urgency of control (Andres

1973).

Biological weed control has been most successful against introduced perennial plants that are dominant over extensive areas in habitats of low disturbance (Andres 1973). Since waterhyacinth is alien to the United States, its abundance may be directly related to absence of effective natural enemies.[15]

The survey of waterhyacinth for natural enemies was started by Ing. Agr. Aquiles Silveira Guido in Uruguay under a PL-480 project, resulting in discovery of 4 insect and 1 mite species with potential for biological control of waterhyacinth. Testing of these species began in 1968 at the USDA Laboratory in Hurlingham, Argentina.[15]

Control with *Neochetina* spp.

Neochetina species are specific to the Pontederiaceae (O'Brien 1975) with *N. eichhorniae* and *N. bruchi* Hustache on waterhyacinth, and *N. affinis* Hustache on *Eichhornia azurea* (Mart.) Kunth. An insect's host range can be precisely determined if the visual, tactile and chemical stimuli used by the insect species for finding and accepting the host plant are known. If all these are characteristic of only 1 host plant, only that will be attacked (Harris and Zwölfer 1968). Some Pontederiaceae fulfill these requirements for *Neochetina* spp., as some of these bagoine weevils occur in Guyana,

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[15] Andres, L. A. 1971. Summary of the biology and host specificity of *Neochetina eichhorniae* Warner, a weevil to control the waterhyacinth, *Eichhornia crassipes*. USDA Tech. Rept. 9 p.

Brazil, Uruguay and Argentina from both Eichhornia spp. and Reussia spp.[16] and were found to be host specific in tests in Trinidad (Bennett 1968a).

The chevroned waterhyacinth weevil, N. bruchi, as it was originally described (Hustache 1926), was actually composed of both the mottled waterhyacinth weevil, N. eichhorniae, plus N. bruchi (Silveira Guido 1965). It was sometimes more numerous than N. eichhorniae in South America,[15] and had microsporidian and nematode parasites in South America (Andres and Bennett 1975). Bennett (1971) found N. bruchi from Eichhornia spp. and Reussia sp. from Guyana, Brazil, Uruguay, and Argentina. Perkins (1974) listed N. bruchi as a defoliator-external leaf feeder as adults, and noted that it is favored by cooler weather. Five adults can kill an average waterhyacinth plant in 5 days, under laboratory conditions. N. bruchi was first released in the egg stage in the United States at Davie, Florida by Dr. B. D. Perkins and E. S. Del Fosse on 1 July 1974.

N. eichhorniae (Warner 1970) has been reported from Argentina, Bolivia and Trinidad.[17] After N. eichhorniae was separated taxonomically from N. bruchi, the former species was studied from 1968-1970 at the USDA Laboratory in Hurlingham (province of Buenos Aires) Argentina.[15] It was found to be more abundant than N. bruchi around

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[16]Farinosae: Pontederiaceae.

[17]Perkins, B. D. 1971. Host specificity and biology studies of Neochetina eichhorniae Warner, an insect for the biological control of water hyacinth. USDA Tech. Rept. 26 p.

Sante Fe, Argentina, and has the same parasites in South America as does N. bruchi (Andres and Bennett 1975). N. eichhorniae was shipped from Trinidad and Argentina to India for further quarantine studies (Rao et al. 1972). Some specificity and feeding tests were repeated[18] using N. eichhorniae, and these insects were also found to be restricted to the Pontederiaceae.

The life cycle of N. eichhorniae in Argentina is as follows: eggs are laid in October-November by adults which have overwintered, and hatch in 7-10 days. The white apodous larvae have 3-5 instars and develop in about 2 months (November-January). They pupate in January, and remain in this stage 20-30 days. Adults emerge and begin to feed, creating characteristic 2-4 mm diameter feeding spots.[18] Adults can live 280 days in the laboratory, and a 1:1 sex ratio occurs in the field. There is a positive thigmotrophic response to the crown of the plants and among insects themselves. Females produce a maximum and average of 300 and 50 eggs, respectively, in their lifetimes.[19] Weevils often feign death after being disturbed. The period of egg to adult takes approximately 3 months.

[18] Perkins, B. D. 1972. Host specificity and biology studies of Neochetina eichhorniae Warner, an insect for the biological control of water hyacinth. Tech. Rept. US Army Corps of Engin. 35 p.

[19] Perkins, B. D. 1972. Research leading to introduction of the first of the waterhyacinth insects in the United States. Tech Rept. Interag. Res. Adv. Comm. Meet., Aq. Plant Contr. Sec., US Army Corps of Engin., Houston, TX, October 11-13, 7 p.

Like many other aquatic insects (Usinger 1956), Neochetina spp. have waxy body coatings,[18] and are obligatorily tied to the aquatic environment. Larvae need waterhyacinth roots in which to pupate (Perkins 1974).

Before release in the United States, this species, as well as N. bruchi, was subjected to many tests. Feeding tests were run on 27 species of plants in 14 families, and consisted of starvation, paired plant, and group plant tests.[18] In these tests, significant feeding was noted only on Sparganium americanum Nutt.[20] and waterhyacinth, and larvae couldn't live on the former species.

The only known enemies of Neochetina spp. are the fungi Beauveria sp.[21] and Aspergilus sp.,[21] 2 mites which may attack pupae, and possibly a microsporidian.[22] Competition with snails[18] and 2 scarabs (Cyclocephala sp. and Dyscinetus sp.)[23] may be important.

Permission from the USDA Working Group on Biological Control of Weeds to release N. eichhorniae came in 1972.[19] An unknown number of weevils were released in Ft. Lauderdale, Florida, on the 23rd of August, 1972 (Anonymous 1972a, b, and Perkins, pers. comm.), with an estimated 20-30% surviving to adults (Perkins 1973b).

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[20]Pandales: Sparganiaceae.

[21]Moniliales.

[22]Sporozoa: Microsporidea.

[23]Coleoptera: Scarabaeidae.

The technique for release is well developed, and spread and increase in the field has been studied.[24]

Damage to plants by Neochetina spp. occurs mainly nocturnally; insects are quiescent during the day and spend time in the crown of the plant. Adults can withstand submersion for several minutes, but will drown if the perios is prolonged.[18, 19] Each adult can produce about 20 feeding spots/day, and there are up to 5 larvae/ plant (Perkins 1974). This feeding damage has been reported to open plants to attack by pathogens and saprophytes. It has been noted that N. eichhorniae affects vigor and growth of the plant (Perkins 1973b, 1974). Hudson (1973) said that "to date, the most effective tool has been insect attack," such as that caused by weevils.

Before weevils were released, several beneficial effects were thought to accrue through the use of these curculionids.[25] These included

(1) opening of large areas of water for recreational uses;

(2) increase in efficiency of water distribution and flood control systems;

(3) reduction in areas for mosquito breeding;

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[24]Perkins, B. D. 1974. Research on insect biological control against waterhyacinth. USDA Tech. Rept. 11 p.

[25]Coulson, J. R. 1972. Potential environmental effects of the introduction of the Argentine waterhyacinth weevil, Neochetina eichhorniae into the United States. Tech. Rept. Interag. Res. Adv. Comm. Meet., Aq. Plant Contr. Sec., US Army Corps of Engin., Houston, TX, October 11-13, 19 p.

(4) increase in DO in water;

(5) increase in utility of water for potable irrigation, fish and wildlife areas; and

(6) reduction or elimination of the need for chemical or mechanical control.

Adverse effects of the introduction were thought to possibly be[25]

(1) aesthetic loss of flower beauty;

(2) increase in other aquatic weeds;

(3) temporary increase in amount of organic matter in water; and

(4) limited feeding on pickerelweed.

Alternatives to biological control of waterhyacinth were thought to be[25]

(1) continuation of chemical or mechanical control;

(2) possibility of mechanical harvesting and utilization;

this is bio-control ?

(3) possible use of natural enemies, including <u>Arzama densa</u> Walker[26] and <u>O. terebrantis</u>;

(4) use of fish and/or snails; and

(5) no control at all.

<u>Control with Orthogalumna terebrantis Wallwork</u>

<u>Orthogalumna</u> is a small genus of galumnid mites known only

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26 Lepidoptera: Noctuidae.

from Madagascar, southeastern North America, Central and South America. O. terebrantis is found on waterhyacinth in the latter 3 regions (Balough 1960). The waterhyacinth mite was described by Wallwork (1965) using Balough's (1961) generic descriptions of oribatoids. This mite was originally thought to be in the genus Lepotgalumna, and earlier references used this genus (Bennett 1968a, b). O. terebrantis is found on E. azurea and Pontederia cordata L.[16] as well as on waterhyacinth, but not on other unrelated plants.

The waterhyacinth mite is one of very few phytophagous oribatoids (Cordo and DeLoach 1975); most feed on fungi, algae, lichens, decaying plant material and rarely on tissues of higher plants (Wooley 1960). The average body length is 440.7 u and average width at the widest point is 237.4 u (Wallwork 1965). This species damages waterhyacinth in Uruguay,[27] other parts of South America (Bennett 1970b, Bennett and Zwölfer 1968, Coulson 1971), the United States[28] (Bennett 1970a) and has been introduced and established in Zambia (Bennett 1974a).

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[27] Silveira Guido, A. 1965. Natural enemies of weed plants. Final Report, Dept. Sanidad Vegetal, Univ. de la Repurblic, Montevideo, Uruguay.

[28] Gordon, R. D., and J. R. Coulson. 1971. Report of field observations of arthropods on waterhyacinth in Florida, Louisiana and Texas, July 1969. In Gangstad et al. Tech. Rept. of the Potential Growth of Aquatic Plants of the cross Florida Barge Canal, Rev. of the Aquatic Plant Contr. Res. Prog. and Summary of the Res. Area Dev. Oper., in Fl. US Army Corps of Engin. 191 p.

The first investigations of O. terebrantis were made in Uruguay.[27] In laboratory testing, the waterhyacinth mite fed significantly only on waterhyacinth, among 17 plants tested.[17] Nymphs and larvae make narrow elongate mines in the pseudolaminae (the waterhyacinth "leaf" is not a true blade, but an extension of the petiole; a pseudolamina (Arber 1920)). These tunnels frequently number more than 50/pseudolamina, and damage a large per cent of tissue (Bennett 1968a, Perkins 1973a, Cordo and DeLoach 1975). Del Fosse et al. (1975) and Del Fosse and Cromroy (1975) found that adult mites could enter pseudolaminae to feed, whereas Cordo and DeLoach (1975) did not. Strain differences and experimental technique may have produced these conflicting results, since the Argentine-Uruguayan strains had also been observed to penetrate pseudolaminae as adults (Perkins 1973a, Cordo and DeLoach 1975).

According to Perkins (1974) the waterhyacinth mite is the only pseudolamina tunneler on waterhyacinth, although the tunneler Eugaurax sp.[29] has subsequently been found (Sabrosky 1974). Number of mines may exceed 500/pseudolamina in heavy infestations (Perkins 1973a) and there may be more than 20,000 mites/m^2.

In oviposition tests, 21 plants in 13 families were used, and mites laid eggs in waterhyacinth and none of the other plants (Cordo and DeLoach 1975). For these reasons the waterhyacinth mite has been considered to be one of the 4-5 most promising biological control agents on waterhyacinth (Bennett 1968a, b, Coulson 1971, Perkins

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[29]Diptera: Chloropidae.

1973a).

Dr. Fred Bennett of the Commonwealth Institute of Biological Control first found the waterhyacinth mite in the United States (Bennett 1968b).[24] It may have been brought into Florida when waterhyacinth was introduced, over 90 years ago (Perkins 1974), but this is uncertain. It may have moved from Mexico along the Gulf coast on an alternate host, such as pickerelweed. This suggestion has even less credibility, since the mite's absence from waterhyacinth in the region of Mexico City (Perkins, pers. comm.) refutes this argument.

The Florida strain of the waterhyacinth mite had been thought to be restricted to shady areas[33] but Perkins (1973a) found that although immatures are sometimes trapped and killed inside pseudo-laminae in the sun, sunny and shady areas are attacked equally. Cordo and DeLoach (1975) found that the Argentine strain was more host specific than the United States' or Uruguyan strains. In the United States O. terebrantis was noted feeding as much or more on Pontederia than Eichhornia[33] but Perkins (1973b) didn't find it on either E. azurea or P. lanceolata Nutt. growing adjacent to heavily-infested stands of E. crassipes in Argentina. Larval mines were found to be more concentrated with the Florida strain than the Argentine strain, without the concomitant increase in damage (Perkins 1973a).

The life cycle of the waterhyacinth mite in Argentina is as follows: adults oviposit in separate waterhyacinth laminae,

inserting eggs approximately every fourth lamina. Nymphal and larval stages develop and tunnel within the leaf, producing 2-7 apically-directed tunnels for each 1 petiole-directed tunnel. Tunnels reach an average length of 5 mm before the adults emerge. From egg to adult takes about 10 days. The emerged adult may feed at the spot where mining occurred, may enter an old tunnel to feed, or may feed in scars created by other animals or abrasions caused by any means. The number of adult tunnels is negligible compared to the number of larval tunnels. From 4 pseudolaminae, Perkins (1973a) found a ratio of 1 adult: 5 nymphs: 10 larvae. Most tunnels are occupied by a single nymph or larva. There is no sexual dimorphism.

The only enemies of the waterhyacinth mite that have been recorded are predaceous mites. As with Neochetina spp., the waterhyacinth mite needs the presence of water, and will die in less than 1 day without it (Perkins 1973a).

Both the mottled waterhyacinth weevil and the waterhyacinth mite, although they may feed slightly on other plant species, fill the criteria for introduction as biological control agents in both safety and specificity, as described by Huffaker (1964). He stated (p. 646)

> It is unreasonable to insist that an insect [or other arthropod] be unable to engage in any feeding on some economic plant under forced or unnatural stress. The capacity to breed on a given plant is the main criterion.

Other Arthropods on Waterhyacinth

Many people have collected or identified arthropods from waterhyacinth and related aquatic plants[19, 30-33] (Blatchley 1920, Leonard 1926, Rehn 1952, 1959, Sabrosky 1950, 1974, Kapur and Dutta 1952, Forbes 1954, Zolessi 1956, Cooreman 1959, Sankaran et al. 1966, Bennett 1968a, b, 1970a, b, 1972a, b, 1974a, b, Bennett and Zwölfer 1968, Vogel 1968, Bennett 1971, Pieterse 1972, Vogel and Oliver 1969a, b, Alden 1971, Coulson 1971, Johnson 1971, Ultsch 1971, 1974, Perkins 1972, 1973a, b, 1974, Brown and Spencer 1973, Silveira Guido 1971, Sankaran and Rao 1972, Silveira Guido and Perkins 1975). Goin (1943) studied lower vertebrate fauna from waterhyacinth. From these investigations, various recommendations for further study have developed.

Bennett and Zwölfer (1968) recommended that 6 species of arthropods should be studied further for biological control of

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[30] Rao, V. P. 1963. US PL-480 Project: Survey of natural enemies of witch weed and water hyacinth and other aquatic weeds affecting waterways in India. CIBC Rept.

[31] Rao, V. P. 1964. US PL-480 Project: Survey of natural enemies of witch weed and water hyacinth and other aquatic weeds affecting waterways in India. CIBC Rept.

[32] Rao, V. P. 1965. US PL-480 Project: Survey of natural enemies of witch weed and water hyacinth and other aquatic weeds affecting waterways in India. CIBC Rept.

[33] Spencer, N. R. 1975. Report on the biology and host specificity of _Epipagis albiguttalis_. USDA Tech. Rept. 11 p.

waterhyacinth, viz. Acigona ignitalis Hmps.,[34] Epipagis albiguttalis Hmps.,[38] Cornops longicorne (Bruner),[35] N. bruchi, Thrypticus sp.,[36] and O. terebrantis. Bennett (1968a) also found that Arzama densa was "adequately host specific and . . . destructive to warrant further investigation," but Habeck (1975) cautioned against introduction of this noctuid without further study because it is a pest of dasheen, Calocasia esculenta L.[37]

Other invertebrates besides insects live in and around waterhyacinth mats. O'Hara (1967) found over 44,000 specimens of over 55 species from 11 samples of waterhyacinth growing around Lake Okeechobee, Florida, with the scud Hyalella azteca (Saussure)[38] the most abundant. Katz (1967) also found that Hyalella sp. was abundant in waterhyacinth, comprising 20-80% of the organisms found there. These and other amphipods are important in the diets of fresh water fish (Huish 1957, McLane 1955, Hansen et al. 1971). Microorganisms in waterhyacinth roots may add to NO_3^--N decreases in eutrophic waters (Dunigan 1974, Dunigan and Shamsuddin 1975).

Control with Pathogens

The use of pathogens as biological control agents is steadily

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[34] Lepidoptera: Pyralidae.

[35] Orthoptera: Acrididae.

[36] Diptera: Dolichopodidae.

[37] Spathiflorae: Araceae.

[38] Amphipoda: Palaemonidae.

gaining popularity (Daniel et al. 1973, Timmons 1970, Hasan 1973, 1974). Many pathogens attack waterhyacinth, especially after attack by insects.[39] Several people are studying pathogens for use against waterhyacinth (Nag Raj 1965, Nag Raj and Ponnappa 1970, Ponnappa 1970, Coulson 1971, Zettler and Freeman 1972, Charudattan 1972).

Acremonium (Cephalosporium) zonatum (Saw.) Gams.[40] is the fungus with perhaps the greatest potential for control of waterhyacinth (Charudattan and Perkins 1974, Padwick 1946, Rintz 1973, Charudattan 1975). Another pathogen with seemingly good potential for biological control of waterhyacinth is Cercospora sp.[40, 41] Other pathogens being studied include Fusarium roseum (Lk.) Snyder and Hansen[40] (Rintz and Freeman 1972), Alternaria eichhorniae var. floridana Nag Raj and Ponn.[42] (McCorquodale et al. 1973, Charudattan 1975), Rhizoctonia solani Kuehn[43] (Freeman and Zettler 1971, Joyner and Freeman 1973, Joyner 1972, Matsumoto et al. 1933, Nag Raj 1965,

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[39]Coulson, J. R. 1972. Potential environmental effects of the introduction of the Argentine weevil, Neochetina eichhorniaė, into the United States. Tech. Rept. Interag. Res. Adv. Comm. Meet., Aq. Plant Contr. Sec., US Army Corps of Engin., Houston, TX, 19 p.

[40]Moniliales: Tuberculariaceae.

[41]Conway, K. E. 1975. Successful field testing of a fungal pathogen as a biological control of water hyacinth. Paper presented at Annu. Meet. Hyacinth Contr. Soc., San Antonio, TX, 7 July.

[42]Moniliales: Dermatiaceae.

[43]Mycelia Sterilia.

Charudattan 1972), Uredo eichhorniae Frag. and Cig.[44] (Charudattan 1975), Bipolaris (Helminthosporium) sp.[42] (Charudattan 1975), and Myriothecium roridum[45] (Charudattan 1972).

Many people hope that a sufficiently virulent phase of one or more of these pathogens may be found or developed. The thought has been expressed that "surely pathogens could save the State of Florida a barrel of money in the fight on water hyacinths— not for one year, but from now on" (Anonymous 1972a).

Control with Other Biotic Agents

Phytophagous fish, such as the white amur, Ctenopharyngodon idella Valenciennes,[12] and Tilapia spp. are also being investigated for biological control of waterhyacinth (Blackburn et al. 1971, Avault 1965, Van Zon 1974, Baker et al. 1974, Kilger and Smitherman 1971, Druijff 1974, Del Fosse et al. 1976). Use of the combination of the white amur and the mottled waterhyacinth weevil have been conducted (Del Fosse et al. 1976) and further studies utilizing these primary consumers are planned.

Phytophagous mammals, especially the manatee, Trichechus trichechus L.,[46] have been considered for use in biological control, but have many drawbacks for waterhyacinth catrol (Druijff 1974,

[44]Uredinales: Pucciniaceae.

[45]Moniliales.

[46]Sirenia: Trichechidae.

Blackburn and Andres 1968), as do goats, Capra sp.,[47] and sheep, Ovis sp.,[47] which have been used for weed control along ditchbanks (Druijff 1974). Water buffalo, Bubalus sp.,[47] have recently been investigated for waterhyacinth control in Gainesville, Florida.

Snails, such as Pomacea australis (d'Orbigny)[48] and Marisa cornuarietis L.[48] feed on waterhyacinth as well (Hunt 1958, Seaman and Porterfield 1964, Blackburn and Andres 1968).

Manipulation of Natural Enemies and Population Modeling

Climatic influences often determine the success or failure of phytophagous insects in controlling pest plants (Harris and Peschken 1974, Andres and Goedon 1971). Natural enemies may kill, slow or prevent establishment or reduce impact of plants, as may the amelioration of plant-insect climatic synchronization (Annecke et al. 1969).

When dealing with large populations of phytophagous insects, as with N. eichhorniae, or mites, as with O. terebrantis, interspecific and/or intraspecific competition may influence their combined effects. These factors can be measured (Bendixen 1975).

Several hypotheses of population interaction are available based on number of attacks by an individual with respect to prey density. Several of these theories will be investigated to determine whether my results support them.

Thompson (1924, 1929) theorized that predators and parasitoids

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[47]Artiodactyla: Bovidae.

[48]Ctenobranchiata: Ampulariidae.

can easily find their prey, and attacks are only limited by the consumption capacity of the predator or available eggs of the parasitoid. Thus, in the Thompsonian theory, number of attacks is constant, and is unrelated to prey density.

Nicholson (1933) and Nicholson and Bailey (1935) said that the number of attacks by an individual for any prey density depends only on the searching ability of the predator. This ability is constant for the species, so fulfilling the appetite ("consumption capacity") of the predator or using all eggs of a parasitoid is unimportant. Total prey killed would then be directly proportional to prey density (ease of finding prey), and per cent killed is constant. These authors emphasize subtractive processes such as intraspecific competition and other density-related phenomena.

Based on empirical data, Holling's (1959) disc equation is the best representation of population change due to predator effects. Under this theory, as prey density increases, number killed increases at a progressively reduced rate. Per cent killed then, would decline under this concept, albeit less drastically than under the Thompsonian theory.

A typical vertebrate sigmoid curve and population lag response has also been found for some insect populations. Haynes and Sisojevic (1966) found such a curve to apply for Philodromus rufus Walchenaer[49] predation upon Drosophila sp.[50] and Embree

[49]Araneae: Thomisiidae.

[50]Diptera: Drosophilidae.

(1966) found such a response for a tachinid parasite, Cyzenis albicans (Fall.)[51] attacking the winter moth, Cheimatobia brumata L.[52]

Andrewartha and Birch (1954) considered that intrinsic favorableness of the environment determined population numbers, whereas Milne (1962), while aware of the importance of environmental conditions, emphasized the importance of density-related subtractive processes.

Chitty (1960) was more concerned with intrinsic species attributes, and theorized that there is an inverse relationship between vitality of individuals and population density, which can also be part of the mechanism of population fluctuation.

Pimentel (1961) suggested that Nicholsonian density-stabilizing mechanisms are replaced during evolution be genetic feedback predator-prey mechanisms, thus emphasizing mutual adaptation between species, their predators and their food plants.

Perkins (1965) found that as tingid[53] populations increased, moth[52] populations on Lantana[54] decreased. He attributed this mortality to tingid-caused leaf abscission.

Debach (1971) theorized that after introducing many enemies against a pest species, the most "effective" one will be predominant,

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[51]Diptera: Tachinidae.

[52]Lepidoptera: Geometridae.

[53]Hemiptera: Tingidae.

[54]Tubiflorae: Verbenaceae.

and cites his work with Aphytis spp.[55] as empirical evidence. Whether this theory will hold true when one considers the introduction of many primary consumers on a pest weed (such as Neochetina spp., O. terebrantis, etc. against waterhyacinth) remains to be proved.

Very little in the way of population modeling has been done on any aquatic plant. Ewel et al. (1975) developed a theoretical model for the impact of waterhyacinth on the environment, but a model for the impact of phytophagous insects on waterhyacinth has not been developed.

The lack of information concerning biological control of aquatic weeds and interaction of species indicated by this literature review points to research that is needed. The experiments described below are an attempt to fill part of this void.

[55] Hymenoptera: Aphelinidae.

RELEASE OF THE MOTTLED WATERHYACINTH WEEVIL

Methods and Materials

Seven hundred field-collected (in northern Ft. Lauderdale, Florida) adult mottled waterhyacinth weevils were released on a waterhyacinth mat infested with waterhyacinth mites (Figure 1, point X). This release was made on 11 June 1974, and consisted of about 350 females: 350 males. The mat of waterhyacinth was located approximately 7 mites west of the USDA Aquatic Plant Management Laboratory in Davie, Florida (Figure 2, point A), in a canal on SW 31st Street (Figure 2, point B) off Hiatus Road, in Davie. All weevils were released in a 0.3 m area on 1-2 plants.

Once each week for 50-weeks the following data were taken from 1 randomly selected plant/area for each of the 10 areas (Figure 1):

(1) number of adult weevils (female, male and total)/plant;

(2) average number of adult waterhyacinth mites/pseudolamina;

(3) number of healthy and senescent pseudolaminae/plant;

(4) age and number/cm^2 of mite nymphal and larval tunnels and weevil feeding spots (determined on most dense areas of tunnels or feeding spots/ pseudolamina);

(5) average pseudolamina dimensions (width and length)/plant;

(6) average petiole length/plant (determined by selecting an average length petiole, after considering all petioles on the plant);

(7) average root length/plant (determined by length of longest primary root/plant);

(8) other arthropods/plant; and

Figure 1.— Schematic view of waterhyacinth mat on which 700 adult *Neochetina eichhorniae* Warner were released. X= point of weevil release; A-C= points of collection of water samples; and 1-10= areas of weekly plant sampling.

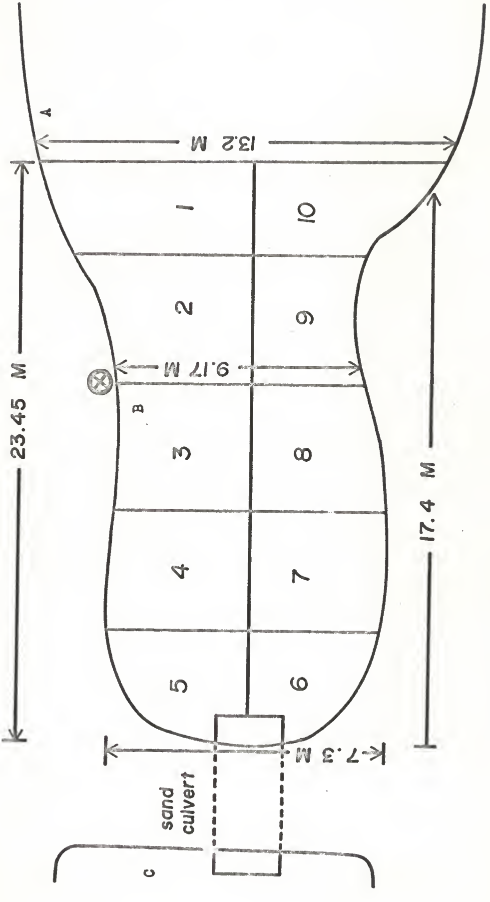
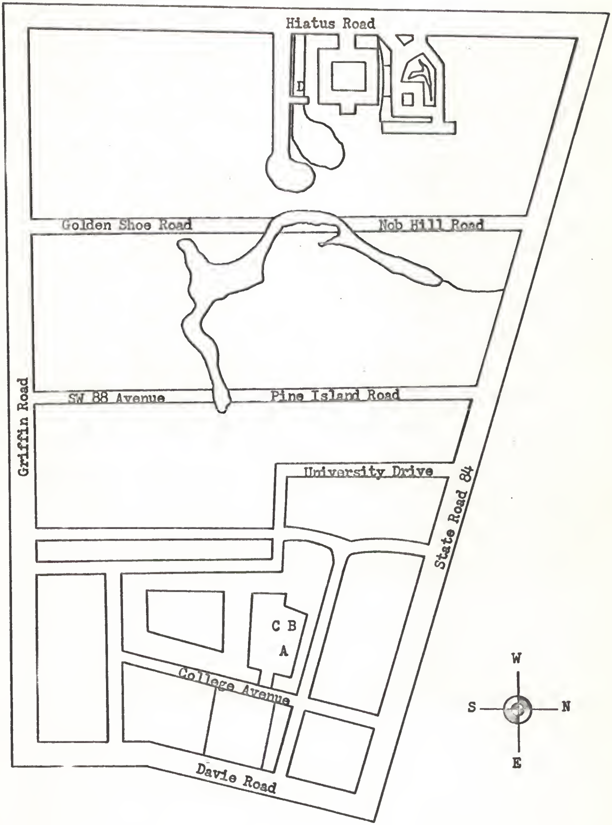

A
13.2 M
23.45 M
9.17 M
B
17.4 M
1
2
3
4
5
6
7
8
9
10
7.3 M
sand culvert
C

Figure 2.— Aerial view of Davie, Florida, indicating location of USDA Aquatic Plant Management Laboratory (A), Official United States Weather Station (B), coffin-holders (C) and mat used for release study of Neochetina eichhorniae Warner (D).


Hiatus Road
D
Golden Shoe Road
Nob Hill Road
SW 88 Avenue
Pine Island Road
Griffin Road
University Drive
State Road 84
C B
A
College Avenue
Davie Road
W
S
N
E

(9) plant density/m^2 (taken monthly at release point, and at all areas after 50 weeks.

In addition, water depth, air temperature (with Weksler® maximum-minimum thermometers), relative humidity (RH; with a H. J. Green® hygrothermograph) and rainfall (with a Belfort Instrument® gauge) were recorded weekly at the Official United States Weather Station at the USDA Laboratory in Davie (Figure 2, point B). All instruments, except Weather Station equipment, were calibrated initially and recalibrated after 6 months and again after 12 months.

Age of mite tunnels and weevil feeding spots was rated on a subjective scale of from 1-4. For mite tunnels, these ages corresponded to tunnels containing an egg or larva, proto- or deutonymph, tritonymph, or emerged adult (after creation of emergence hole), respectively. For weevil feeding spots, the corresponding scale was less than 1 week old, 1-2 weeks old, 2-3 weeks old, and greater than 3 weeks old, respectively. Associated with age 1 feeding spots was a pale green color, heavy exudate and presence of adult waterhyacinth mites; with age 2 feeding spots, a dark green color, little or no exudate, and few or no adult waterhyacinth mites; with age 3 feeding spots, a light brown color, no exudate and no adult waterhyacinth mites; and with age 4 feeding spots, a dark brown color, no exudate and no adult waterhyacinth mites. Age 1 tunnels averaged 0.5 mm in length; age 2 tunnels, 1.0 mm; age 3, 1.5 mm; and age 4, 2.0 mm.

For computer analyses, in which meristic data can most effectively be handled, number of mite tunnels/cm^2 was multiplied by tunnel age (equation 1) to give an Orthogalumna Damage Index (ODI).

$$ODI = (\text{no. tunnels}/cm^2)(\text{age of tunnels}) \qquad (1)$$

Neochetina Damage Indices (NDI) were computed by equation 2.

$$NDI= (\text{no. feeding spots/cm}^2)\left[5 - (\text{age of feeding spots})\right] \quad (2)$$

Rationale behind these indices is as follows: as mite tunnels get longer (i.e. as mites grow to adults and emerge), damage to the plant successively increases. Thus, tunnels of age 4 are more damaging to the plant (partly because they bear the opening of the tunnel which the adult mite prepared in its emergence, which allows development of pathogens and saprophytes) than are tunnels of ages 1, 2 or 3 (assuming equal numbers of tunnels of each age). Directly multiplying verage age of tunnels by their density/cm^2 gives a reasonable estimate of the damage done to the plant by mite tunnels. Conversely, recent weevil feeding spots are more damaging to the plant than are old feeding spots because they cause increased desiccation and attract mites and weevils. Thus, direct multiplication of age by density would be negatively correlated to effect, and would be the opposite of the mite scale. To put both mite and weevil damage on a similar scale then, a weevil feeding spot of age 4 is made meristically equal to a mite tunnel of age 1 by subtracting 4 from 5 (5 - 4= 1), and so on. This is not to imply that the same damage is done to the plant by a weevil feeding spot and mite tunnel of the same age; this computation only places mite and weevil damage on a similar scale.

When these data are handled in this manner, relative damage to the plant by mites and weevils can be compared, and only 1 number each/plant/site/day need be recorded for mite and weevil damage,

respectively.

Plant measurement factors (PMF) were calculated for each area on the mat by the formula in equation 3.

$$PMF = \frac{(PsW + PsL + PL)}{RL} \qquad (3)$$

Parameters in equation (3) are as follows: PsW= pseudolamina width; PsL= pseudolamina length; RL= root length; and PL= petiole length. All above measurements are given in cm.

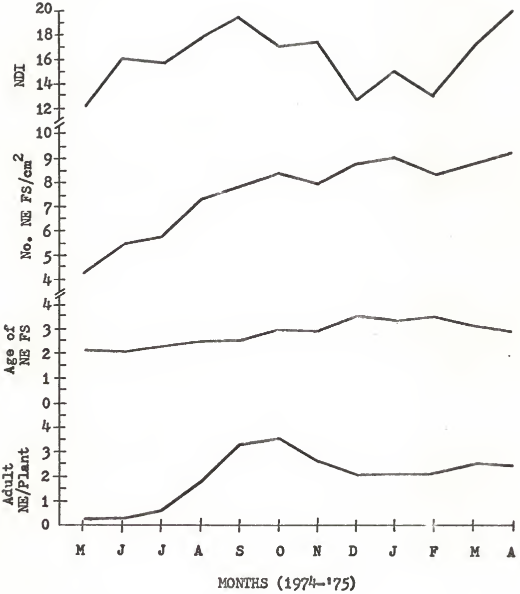
Air temperature, RH and rainfall were taken daily at the Official U. S. Weather Station in Davie. Weekly averages were then computed for each week. Photographs of the site were taken monthly and aerial (helicopter) pictures were taken after week 50. This and all following experiments were analyzed statistically. Analyses of variance and Duncan's Multiple Range Tests (Duncan 1965) were applied where appropriate, as were regression, multiple and canonical correlation, and plotting procedures.

A waterhyacinth mat without weevils, but with a "natural" (i.e. population not manipulated directly by man) population of mites was sampledas was the experimental mat for comparison purposes.

Results and Discussion

For the first 3 months, numbers of adult weevils/plant were low and sporadic (Figure 3). This was due to the low number of weevils released (700). After 3 months (the time for first generation weevil adults to emerge) number of adults recovered/plant began to increase. Increase in number of weevils found on the plants appeared to level off by October (Figure 3), and decrease slightly after that. However,

Figure 3.— Monthly trends of *Neochetina eichhorniae* Warner (NE) populations and damage data after NE release on a waterhyacinth mat infested with *Orthogalumna terebrantis* Wallwork. FS= feeding spots; NDI= [5 - (age of NE FS)](no./cm^2).


NDI
20
18
16
14
12
No. NE FS/cm²
10
9
8
7
6
5
4
Age of NE FS
4
3
2
1
0
Adult NE/Plant
4
3
2
1
0
M J J A S O N D J F M A
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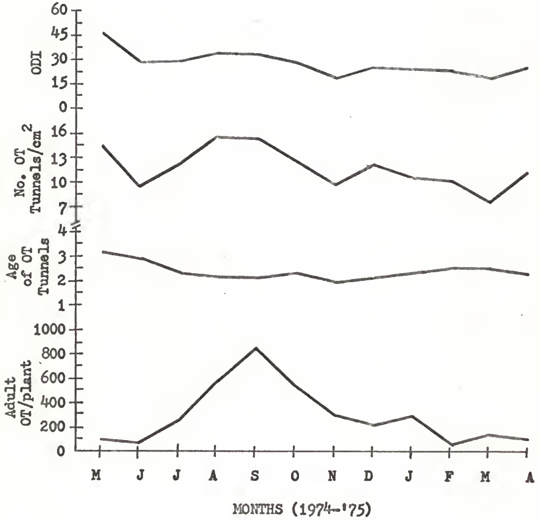
because adult waterhyacinth weevils are concentrated around areas of new feeding, possibly because of the release of a kairomone (see p. 109), number of adults is not a reliable measure of the weevil population. Number of weevil feeding spots/cm^2 is a more reliable measure of the weevil population, and this index increased steadily throughout the 12-month period (Figure 3). Increase in number of weevils of all life stages is nearly geometrical in shape, and more accurately gauges the stress applied to waterhyacinth by weevils. After 50 weeks, there were approximately 2.25 million weevils of all life stages, based on an average egg production of 50/female and an 80% egg to adult mortality. This number may be considerably higher than the actual number of weevils on the mat, but is the best estimate based on the life history information now at hand.

Fluctuations of the waterhyacinth mite population were closely related to certain abiotic factors, especially temperature and evaporation. As temperature began to decrease, numbers of adult mites, then number of mite tunnels, also decreased (Figures 4-6).

Adult waterhyacinth mite populations were temporarily reduced at week 6 (from the previous week's average of 95/plant to 42/plant) by a light spray of malathion applied by a helicopter pilot spraying citrus in a neighboring grove. He had flown over our canal to see what we were doing, but momentarily forgot to turn off his spray rig. Immature mites inside closed tunnels at the time of this spray were apparently not affected. Populations of adult mites had

Figure 4.— Monthly trends of Orthogalumna terebrantis Wallwork (OT) populations and damage data on a waterhyacinth mat containing Neochetina eichhorniae Warner. ODI= (age of OT tunnels)(no. tunnels/ cm^2).



60
45
30
15
0
ODI
16
13
10
7
No. OT Tunnels/cm^2
4
3
2
1
Age of OT Tunnels
1000
800
600
400
200
0
Adult OT/plant
M J J A S O N D J F M A
MONTHS (1974-'75)

Figure 5.— Monthly trends in air temperature ($^{\circ}C$) taken at Official United States Weather Station and above concrete coffin-holders, Davie, Florida.

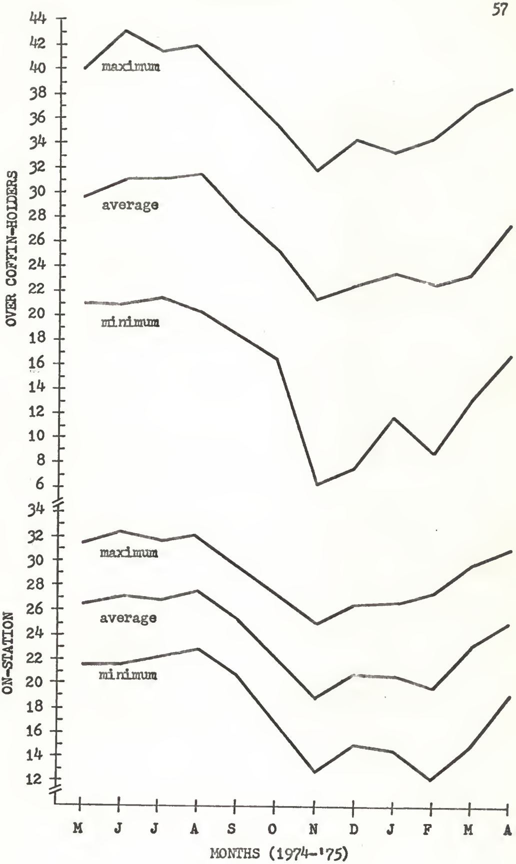
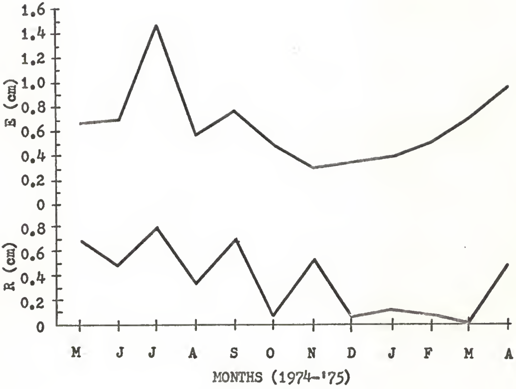

44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
34
32
30
28
26
24
22
20
18
16
14
12
maximum
average
minimum
maximum
average
minimum
OVER COFFIN-HOLDERS
ON-STATION
M J J A S O N D J F M A
MONTHS (1974-'75)

Figure 6.— Monthly trends in rainfall (R) and pan evaporation (E) taken at Official United States Weather Station, Davie, Florida.



1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
E (cm)
0.8
0.6
0.4
0.2
0
R (cm)
M J J A S O N D J F M A
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increased to pre-spray levels by week 9 (with 118 adult waterhyacinth mites/plant). Weevils were apparently unaffected by the spray because they were in the crown of the plant at the time of the spray.

Monthly averages for all weevil plus mite, and plant data for each individual area, viz. 1-10, are given in Tables 1-10 and 11-20, respectively.[1] The same general trends are shown with the individual areas as in the entire area.

Analyses of variance for statistically significant parameters measured at the release site of _N. eichhorniae_ are given in Table 21. There was a highly significant (P= 0.01) reduction in number of pseudolaminae, pseudolamina width and length, petiole length, root length and PMF, and a highly significant increase in number of adult mottled waterhyacinth weevils, waterhyacinth mites, weevil and mite damage and male and female weevils, over the 50 week period. PMF was also significantly (P= 0.05) different over time. Plant density was reduced from an average of 34 to 26 plants/m^2 for this same period.

Areas of the release mat, viz. 1-10, were highly significantly different for adult mottled waterhyacinth weevils, pseudolamina dimensions, petiole and root lengths, and PMF, and significantly different for number of petioles, waterhyacinth mite damage, and female weevils (Table 21).

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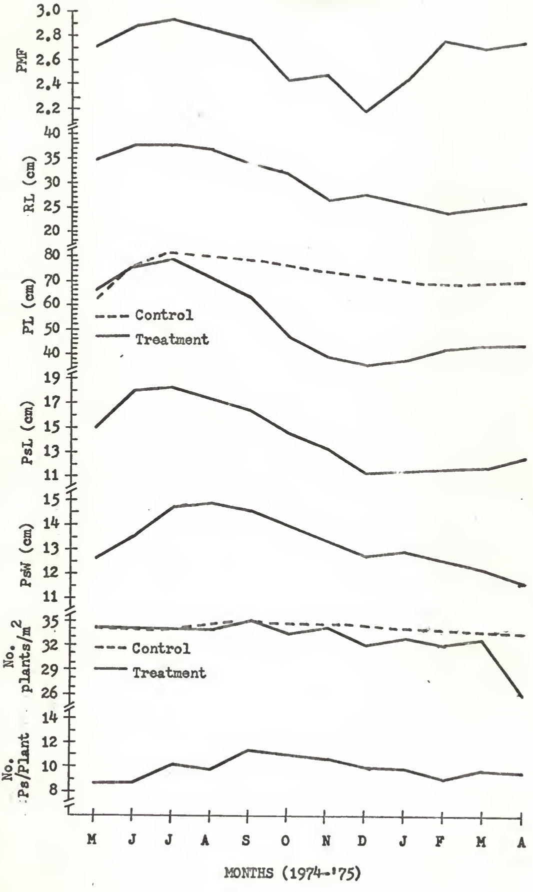
[1]All tables are listed consecutively in the Appendix.

These data indicate 2 important results: first, the combined effects of weevils and mites applied sufficient stress to the plants to bring about a significant reduction in plant size and density (viz. the 30+ cm decrease in petiole length); and second, some factor(s) caused areas 1-10 to be significantly different in some parameters. A closer examination of the mat in the field indicated that areas 1-4 were predominantly shaded, whereas areas 5-10 were in full sun for most of the day. Areas 1-4 had consistently higher numbers of weevils (averages of 2.5/plant, compared to 1.8/plant for areas 5-10) and pseudolaminae (10.1/plant compared to 10.0/plant for areas 5-10), larger pseudolamina width (13.25 cm compared to 13.14 for areas 5-10) and length (14.11 cm compared to 14.04 for areas 5-10), longer root length (13.51 cm compared to 29.08 for areas 5-10), lower mite damage (27.68 compared to 31.04 for areas 5-10), shorter petiole length (52.88 cm compared to 52.97 for areas 5-10), less female weevils (0.94/plant compared to 0.98/plant for areas 5-10), and lower PMF (2.74 compared to 3.01 for areas 5-10) (Tables 1-20). Mites were always more abundant in sunny than shaded areas.

Decrease in pseudolamina dimensions, petiole and root lengths, and number of plants/m^2 closely followed increase in the mottled waterhyacinth weevil population. For the first 3 months of the study, plant size increased (Figure 7) due to the normal summer growth period. By the time of the second emergence of weevil adults, however, a gradual lessening in the heretofore increasing

Figure 7.— Monthly trends of waterhyacinth measurements on a mat containing <u>Neochetina eichhorniae</u> Warner and <u>Orthogalumna terebrantis</u> Wallwork. Ps= pseudolaminae; PsW= pseudolamina width; PsL= pseudolamina length; PL= petiole length; RL= root length; PMF= $\frac{(PsW + PsL + PL)}{RL}$.


PMF
RL (cm)
PL (cm)
PsL (cm)
PsW (cm)
No. plants/m^2
No. Ps/Plant
Control
Treatment
Control
Treatment
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average size of plant parts leveled off, and as later emergences of adult weevils occurred, a dropoff in size of individual plant parts followed.

The best measurement of stress applied to waterhyacinth is seen in the petiole length. This measurement is the most reliable parameter of plant health because, unlike root length (which is greatly influenced by water quality) or pseudolamina dimensions (which do not change appreciably in size), it is the first parameter to be affected. In this experiment, petiole length decreased 30-40 cm over the 50 week period (Figure 7) in the experimental mat, while it increased initially, then leveled off, in the control mat. Plant density also decreased greatly relative to the control mat (Figure 7). Since nutrients were not limiting in the study (e.g. P was greater than 0.1 ppm, pH was around 7, etc.), and inasmuch as no herbicides were applied to the plants, decrease in size of plant parameters can be directly attributed to stress applied by insects and ensuring attack by mites and pathogens.

Adult waterhyacinth mites were very often found feeding in spots created by adult mottled waterhyacinth weevils. This was especially obvious when populations of mites were high, and may have contributed to mite population increase (see p. 109).

Pathogens such as Acremonium zonatum and Cercospora sp. were noted to increase in effect and abundance as the year progressed, and were especially abundant when mite populations were high. A relationship between A. zonatum and arthropods attacking waterhyacinth

has often been suspected. It is usually weevil damage, however, that is said to allow A. zonatum to develop to a greater extent in affected waterhyacinth (Charudattan 1972, 1975).[2] In this study, however, and in all other field and laboratory observations made, no fungal lestion of A. zonatum were found associated with weevil feeding spots. Zonate leaf spot disease of waterhyacinth (caused by A. zonatum) was very abundant in the field and laboratory plants at the time of these observations. In all observed cases, however, fungal lesions developed from age 4 (i.e. after the adult water-hyacinth mite had created an emergence hole) mite tunnels, as clearly seen in all samples. These lesions caused or accelerated drying of waterhyacinth tissue and added to the poor health of the plants.

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[2] Charudattan, R., and B. D. Perkins. 1974. Fungi associated with insect damaged waterhyacinth in Florida and possible effects on plant host population. Paper presented at Annu. Meet. Hyacinth Contr. Soc., Winter Haven, FL, July 1974.

COFFIN-HOLDER TREATMENTS

Methods and Materials

Seven treatments with varying numbers of weevils and mites plus controls were conducted in concrete coffin-holders at the USDA Laboratory in Davie. Coffin-holders (78.75 x 226.05 cm) were initially filled with 750 liters of pond water and 1 liter of 0.5% Hoagland's nutrient solution (Hoagland and Arnon 1950). Nutrients, therefore, were not considered limiting. All coffin-holders had an equal amount of waterhyacinth biomass added initially (equal to 20 small plants). All plants were field-collected in Davie, and washed in 0.1 NaCl solution to kill all biota before mites and/or weevils were added. A pair (1 male: 1 female) of adult waterhyacinth weevils/plant and/or 50 adult waterhyacinth mites/plant were added in the following treatments:

(1) 40 weevils and 1000 mites added simultaneously;

(2) 40 weevils alone;

(3) 1000 mites alone;

(4) 40 weevils established for 3 months, then 50 mites/plant added;

(5) 1000 mites established for 3 months, then 2 weevils/plant added;

(6) covered controls (no weevils or mites added, and coffin-holders screened to prevent immigration); and

(7) uncovered controls.

These treatments will be referred to as (1-7), respectively.

Rationale behind choosing these treatments was as follows: 2 weevils and 50 mites/plant are realistic (perhaps even low) numbers of arthropods that approach levels of these agents that have been released and are

present in the field (Perkins 1973 a, b), and correspond to most of the releases of weevils that have been made. In some cases, however, we may apply weevils to a mat of waterhyacinth without mites, or a mat may exist with only mites; thus treatments (2) and (3). Also, a mat without mites, but with an established population of weevils may come into contact with a mat containing mites (or most mites may have been killed through the action of cold weather or insecticides), and vice verse; thus treatments (4) and (5). In addition, some measure of growth without the stress of arthropods was needed. Since allochthonous arthropods may eventually invade the plants, 1 set of controls, (6), was covered with screening on a wooden frame in an attempt to keep arthropods out. Finally, uncovered controls, (7), were set up to determine growth of plants not stressed by arthropods.

All treatments were replicated in 3 blocks in a randomized complete block design (Figure 8). Blocks consisted of 9 coffin-holders,each, with an empty row of buffer coffin-holders between each block. Treatments (1-6) were replicated once in each block; treatment (7) was replicated 3 times in each block.

Six months into the study an additional aliquot of weevils and mites (same number/plant as before) were added to the experiment to simulate heavy emergences of these arthropods.

The data were sampled following a modified 7-week, or septenary, schedule; i.e. on week 1, all coffins in all blocks were sampled; week 2, block 1; week 3, block 2; week 4, block 3; week 5, blocks

Figure 8.— Experimental design of on-station coffin-holders containing: Neochetina eichhorniae Warner (NE) alone (1); Orthogalumna terebrantis Wallwork (OT) alone (2); NE + OT (3); NE, plus OT after a 3 month delay (4); OT, plus NE after a 3 month delay (5); covered controls (6); uncovered controls (7); and blanks between blocks (8).

6	3	1
7	2	6
4	5	6
8	8	8
6	1	7
4	6	2
5	6	3
8	8	8
2	6	6
4	3	7
6	5	1

1 and 2; week 6, blocks 1 and 3; and week 7, blocks 2 and 3. In each septenary, then, each block was completely sampled 4 times. Sampling during week 8 corresponded to that during week 1; week 9 to week 2; etc. On week 50, all coffins in all blocks were sampled.

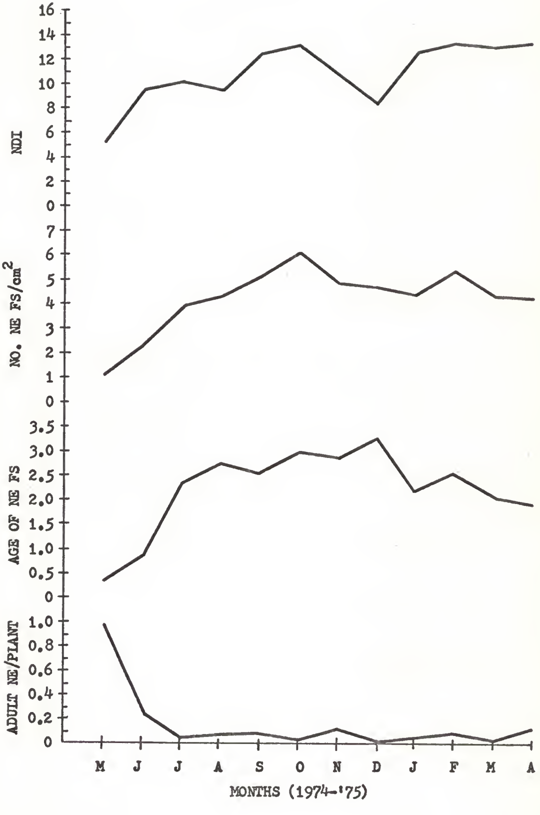
The same data were taken for this experiment as with the release experiment. One plant/coffin-holder was chosen at random/week. From this plant all measurements were taken. The plant was then placed back into the same coffin. Unlike the release experiment, in which plants were slightly broken during weevil collection, plants in this experiment were not torn apart in search of weevils. The only other difference between this and the release experiment was that wet weights of plants were taken weekly, from the plant chosen at random, in this experiment.

Results and Discussion

Monthly trends of mottled waterhyacinth weevils, waterhyacinth mites, plant and pseudolamina measurements, and other plant parameters are given in Figures 9-12, respectively. These figures indicate the trend over all treatments, and represent the average effect of weevils, mites, mite-weevil combinations, and controls on waterhyacinth.

As with the release experiment, number of weevils and mites, plus the weevil feeding spots and mite tunnels, were low and sporadic initially (Figures 9 and 10). Adult weevils/plant decreased sharply after release (Figure 9), whereas weevil feeding spots increased for the first 5 months, then decreased (Figure 9). Number of adult

Figure 9.— Monthly trends of <u>Neochetina eichhorniae</u> Warner (NE) populations and damage data after NE release on waterhyacinth contained in concrete coffin-holders. FS= feeding spots; NDI= $[5 - (\text{age of NE FS})](\text{no. FS/cm}^2)$.


NDI
16
14
12
10
8
6
4
2
0
NO. NE FS/cm^2
7
6
5
4
3
2
1
0
AGE OF NE FS
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
ADULT NE/PLANT
1.0
0.8
0.6
0.4
0.2
0
M J J A S O N D J F M A
MONTHS (1974-'75)

mites/plant followed a similar trend (Figure 10), but did not decline as quickly. Age and number/cm^2 of mite tunnels, and ODI all increased initially, following the adult mite population, then decreased with the decline in adult mites/plant (Figure 10).

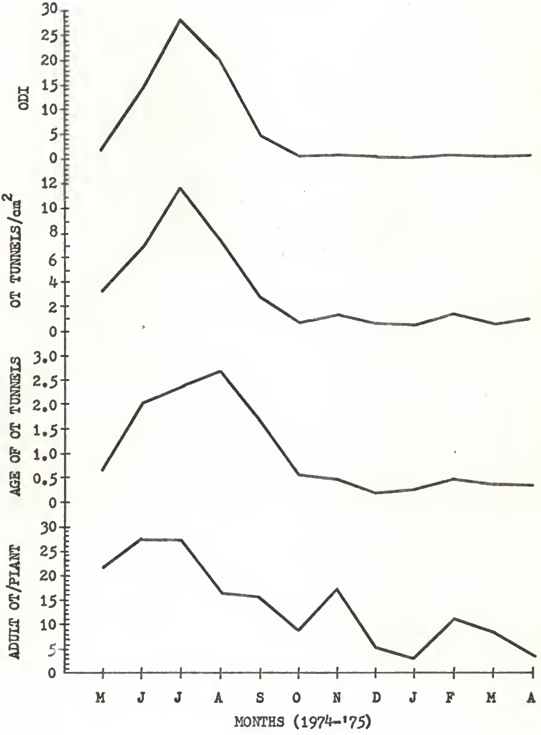
A gradual increase in number of plants/coffin-holder occurred (Figure 11), but since these figures include all treatments (including both covered and uncovered controls), this trend is misleading (see analyses of individual treatments, below). All plant measurements decreased over 50 weeks, viz. pseudolaminae/plant, pseudolamina width and length (Figure 11), petiole and root length, PMF and wet weight (Figure 12).

There was a highly significant difference in mite damage between blocks in septenary 2 and a significant difference between blocks for septenary 3 (Table 22). Mite damage was also significantly different between treatments for septenary 3, as was the block x treatment interaction. Number of adult mites/plant was significantly different between blocks for septenary 3 and 7, and between treatments for septenary 5.

Damage caused by adult weevils was highly significantly different between blocks for septenary 2 and 7, and between treatments for septenary 2 (Table 22).

Number of adult weevils/plant were significantly different between blocks for septenary 4, 6 and 7, and highly significantly different between treatments for septenary 1, and for the block x treatment interaction for septenary 6 (Table 22).

Figure 10.— Monthly trends of Orthogalumna terebrantis Wallwork (OT) populations and damage data after OT release on waterhyacinth contained in concrete coffin-holders. ODI= (age of OT tunnels)(no. tunnels/cm^2).



ODI
30
25
20
15
10
5
0
OT TUNNELS/cm^2
12
10
8
6
4
2
0
AGE OF OT TUNNELS
3.0
2.5
2.0
1.5
1.0
0.5
0
ADULT OT/PLANT
30
25
20
15
10
5
0
M J J A S O N D J F M A
MONTHS (1974-'75)

Figure 11.— Monthly trends of waterhyacinth measurements from plants grown in concrete coffin-holders. Ps= pseudolaminae; PsW= pseudolamina width; PsL= pseudolamina length.

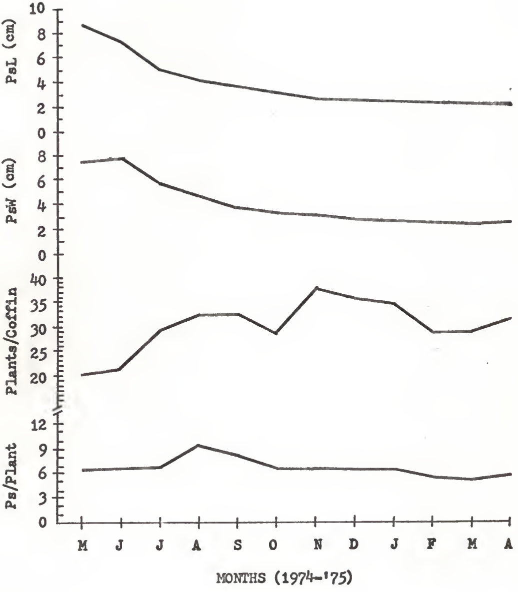
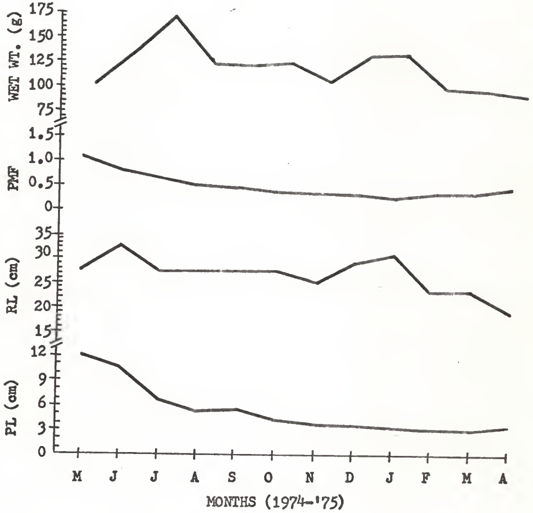

PsL (cm)
PsW (cm)
Plants/Coffin
Ps/Plant
10
8
6
4
2
0
40
35
30
25
20
12
9
3
M J J A S O N D J F M A
MONTHS (1974-'75)

Figure 12.— Monthly trends of waterhyacinth measurements from plants grown in concrete coffin-holders. PL= petiole length; RL= root length; $PMF = \frac{(PsW + PsL + PL)}{RL}$, where PsW and PsL= pseudolamina width and length, respectively.



WET WT. (g)
175
150
125
100
75
PMF
1.5
1.0
0.5
0
RL (cm)
35
30
25
20
15
PL (cm)
12
9
6
3
0
M
J
J
A
S
O
N
D
J
F
M
A
MONTHS (1974-'75)

Number of pseudolaminae/plant was highly significantly different between blocks for septenary 2, 4 and 5-7, and significantly different for septenary 3; a significant difference was found between treatments for septenary 2, 5 and 6; and a significant difference was noted for block x treatment interaction for septenary 4. Petiole length was significantly different between blocks for septenary 2 and 3 and highly significantly different between blocks for septenary 6, between treatments for septenary 2 and 3, and for block x treatment interaction for septenary 3 (Table 22).

Pseudolamina width was significantly different between blocks for septenary 2 and 4, highly significantly different for septenary 5-7, significantly different between treatments for septenary 2, and highly significantly different for septenary 3 (Table 22).

Pseudolamina length was highly significantly reduced for septenary 2 and 7, and significantly reduced for septenary 5 and 6. Root length was highly significantly reduced for septenary 1. Plant density was significantly reduced in septenary 2 and 5-7, and highly significantly reduced for septenary 3 and 5 (Table 22).

Wet weight of waterhyacinth was highly significantly reduced for septenary 2. There was also a significant block difference for spider mites for septenary 2 and 3, between treatments for septenary 2, and a highly significant difference for block x treatment interaction for septenary 2 and 3. PMF was highly significantly different for blocks in septenary 5, and significantly different for septenary 5 and 6; between treatments for septenary 5; and for block x

treatment interaction for septenary 6 there was a highly significant difference (Table 22).

Most of the above-mentioned block differences can be explained by the removal of plants by boat-tailed grackles, Cassidix mexicanus L.[1] For some unknown reason, the birds removed plants in coffin-holders in blocks 1 and 2, with many more plants removed from block 1 than 2, but did not remove plants from block 3. Coffin-holders were covered with 1.8 cm mesh wire screening in septenary 3, after birds were noted removing plants. (Grackles landed on mats at the field site, and were observed to remove some plants. They then fed on the removed plants, or perhaps on arthropods contained thereon.)

Other factors that may also have added to these block differences include: shading (block 1 was shaded for a longer period of time daily by neighboring buildings) and position effects.

Orthogalumna terebrantis Alone

Septenarial averages of population growth of O. terebrantis are given in Table 23. Since the mottled waterhyacinth weevil moved from coffin-holder to coffin-holder, septenarial averages are also given in Table 23 for populations of and damage to waterhyacinth by N. eichhorniae. Similar procedures will be followed in all subsequent analyses.

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[1]Passeriformes: Icteridae.

Number of adult mites was initially high, then dropped off to zero, as did number of mite tunnels/cm^2. Before reduction in mite populations, plant size and weight had begun to decrease (Table 23). This decrease was in part due to stress applied by mites and the few weevils that came onto the plants. This was ascertained by comparison with growth of controls.

The effect that waterhyacinth mites alone had in reducing waterhyacinth, however, was not very great. There was, however, a higher incidence of pathogenic and saprophytic disease on plants with mites alone. The total stress applied by mites, weevils and pathogens contributed to decrease in waterhyacinth size and density.

Neochetina eichhorniae Alone

Population growth of and effect on waterhyacinth of the mottled waterhyacinth weevil is shown in Table 24. Density of weevil feeding spots and NDI increased initially, then decreased (Table 24). This may have been caused by stress applied to plants by weevils, making plants less suitable for attack by weevils. Effect of weevils on waterhyacinth is shown by the steadily decreasing size of plant parts (Table 24). Coffin effect may also have contributed to these decreases (see controls, below).

The mottled waterhyacinth weevil alone caused a greater decrease in number and size of plants than did the waterhyacinth mite, but plants bearing weevils alone were found to be attacked

less strongly by pathogens and saprophytes than were plants bearing mites alone. These results tend to support further use of waterhyacinth mites as biological control agents of waterhyacinth because of their ability to enhance stress by being conducive to establishment and development of pathogens, especially pathogenic fungi such as Acremonium zonatum.

Combination of N. eichhorniae and O. terebrantis

Population growth of both the mottled waterhyacinth weevil and the waterhyacinth mite, and their combined effect on waterhyacinth is shown in Table 25.

As occurred with the previous treatments, numbers of feeding spots and mite tunnels were initially low, reached a peak, then again decreased. This may be due to the plants becoming unsuitable for preferred feeding by either species; by septenary 2, not only had the plants become smaller in size and less dense, but a great deal of disease had been able to enter the plants containing weevils and mites. As a result of all biotic stresses, the combination of weevils, mites and pathogens, the greatest effect on plants was seen with this treatment. In addition, the effect was greater than would be expected if only the additive effects of weevils, mites and pathogens were considered; i.e. biological synergism had occurred. This lends support for similar conclusions reached with the release experiment.

N. eichhorniae Established 3 Months, then *O. terebrantis* Added

Septenarial averages of population growth of mottled waterhyacinth weevils and waterhyacinth mites, plus plant measurements, are given in Table 26. As with prior treatments, mite damage and numbers were greatest in early parts of this treatment, but weevil damage was fairly consistent. All plant measurements decreased significantly over the 50 weeks, albeit not as greatly as in the prior 3 treatments. These results indicate the value of adding *O. terebrantis* to waterhyacinth mats containing only *N. eichhorniae*, because damage by *A. zonatum* and other pathogens and saprophytes increased after mites were added.

O. terebrantis Established 3 Months, then *N. eichhorniae* Added

Septenarial averages of population growth of weevils and mites, plus plant measurements, are given in Table 27. Some individual plant parts decreased in size over the 50-week period, but density of plants increased over this time. Weevils probably didn't have enough time owing to their low numbers on the plants (as compared with the period of time that weevils applied initially to plants had) to exert sufficient stress to lessen density as well as size of plants in the few months that the experiment ran. Levels of pathogens were highest when mite populations were greatest.

These results typify the pre-weevil release stage that is now typical of the majority of the canals and lakes in Florida. Levels of pathogens in these situations are generally low, depending upon the specific conditions in the particular area. Addition of weevils to these areas may cause an increase in number of mites, and in turn, pathogens (see p. 109).

Covered Controls

Population growth of and effect on waterhyacinth of the mottled waterhyacinth weevil and the waterhyacinth mite in coffin-holders which had neither weevils nor mites applied initially, and were covered with screening, is shown in Table 28. Numbers of weevils and weevil damage were very low, but mites were relatively high in number due to exclusion of natural enemies in covered coffin-holders. Plant density increased greatly over the 50-week period, from 20 plants to an average of 88 plants/coffin-holder (Table 28).

Perhaps the greatest effect that the covers had was in allowing the population outbreak of spider mites. As with waterhyacinth mites, when predators of tetranychids were excluded, populations of spider mites increased greatly. Since plant density increased considerably in these coffin-holders, however, effect of tetranychids on waterhyacinth was negligible.

The source of these allochthonous acari, which does not include other predatory mites to a great degree, was probably other waterhyacinth plants on the USDA station.

<u>Uncovered Controls</u>

Population growth of and effect on waterhyacinth of the mottled waterhyacinth weevil and the waterhyacinth mite in control coffin-holders to which neither arthropod was applied are given in Table 29. Number of weevils was greater, and number of mites was less, compared to covered controls (Table 28), and plant growth was less.

Septenarial averages of the above 7 treatments for all data are given in Tables 30 and 31.

MOVEMENT OF ADULT WATERHYACINTH MITES TO PICKERELWEED

Methods and Materials

Waterhyacinth mites are sometimes found on pickerelweed, *Pontederia cordata*. This has been noted especially in the Gainesville area, but rarely in the Ft. Lauderdale area (Perkins, pers. comm.). The conditions under which this occurred were unknown. Four temperature, light and humidity regimes were established in Precision Scientific Freas® Model 818 incubators. These chambers can be calibrated to run dual temperature and light regimes. The regimes chosen were: (1) 5-25°C; (2) 10-30°C; (3) 15-35°C; and (4) 20-40°C. Light was provided by a single fluorescent bulb in each chamber, providing 115, 120 110, and 110 ft-candles, respectively. Lights were on from 8:00 AM-5:00 PM in all chambers. RH varied from 30-80%.

Two hundred adult field-collected waterhyacinth mites were placed on each of 4 mite-free waterhyacinth plants. Each infested plant was then placed next to an arthropod-free pickerelweed plant. Plants were touching to allow movement of mites. Both waterhyacinth and pickerelweed plants were field-collected in Davie and established from 1-2 weeks in each incubator before arthropods were added. Plants were placed in plastic-lined metal tubs, each containing about 2 liters of 0.5% Hoagland's nutrient solution, which was replenished weekly. Thus, nutrients were not considered to be limiting.

Plants were checked weekly for 10-weeks for movement of mites

to pickerelweed. Temperatures and RH were taken weekly with Taylor® maximum-minimum thermometers and a Psycho-Dyne® psychrometer (model 22010), respectively.

Results and Discussion

After 10 weeks, the only mites that moved from waterhyacinth to P. cordata in the incubators were in chambers 1 and 2, with accompanying low temperatures and high humidity. Not all mites in either chamber moved, however. These conditions correspond to those noted in the field at the time of mite movement there. The reason(s) why such waterhyacinth mite movement in the field occurs remains obscure.

Most waterhyacinth mite movement occurred in incubator 2, with a 10-30°C temperature regime and 80% RH. Mites moved onto pickerelweed in incubator 1, with a 5-25°C temperature regime and 30-40% RH only once, immediately after being placed in the incubator. This incubator had been left open in preparing the chamber for the waterhyacinth mites, and had reached the RH of the external air—about 70%. Thus, this one-time movement in incubator 1 may have been a response to external conditions, and not a response to the temperature, RH, and light conditions in the incubator per se. Movement under conditions in incubator 2 was constant, however, as determined by an increasing number of mites on pickerelweed each week in this incubator.

EFFECT OF ADULT WATERHYACINTH MITES ON WEEVIL OVIPOSITION

Methods and Materials

Using the Freas incubators at the settings described above, 3 pairs of weevils (3 females: 3 males) were added to each of 5 pie pans (22.5 cm diameter x 2.5 cm deep). Pie pans were covered with glass plates (23.1 cm^2 x 0.3 cm thick). Each pie pan contained a fresh waterhyacinth pseudolamina inserted in a 7 ml-capacity test tube containing tap water. Pie pan rims were coated with silicone grease (either GHTLIL-L-157-194 Dow® Corning 44 Grease 2150-257-5358-4t-B-194, or 6850-880-7616 Silicone Compound DSA-400-70-C-0337-A-11/69) Lot Ba-207) to prevent mite escape.

To one pie pan-pseudolamina unit in each incubator were added 0, 50, 100, 150 or 200 adult, field-collected waterhyacinth mites. Data were taken weekly for 10 weeks on:

(1) number of dead weevils;

(2) number of waterhyacinth mite adults/plant;

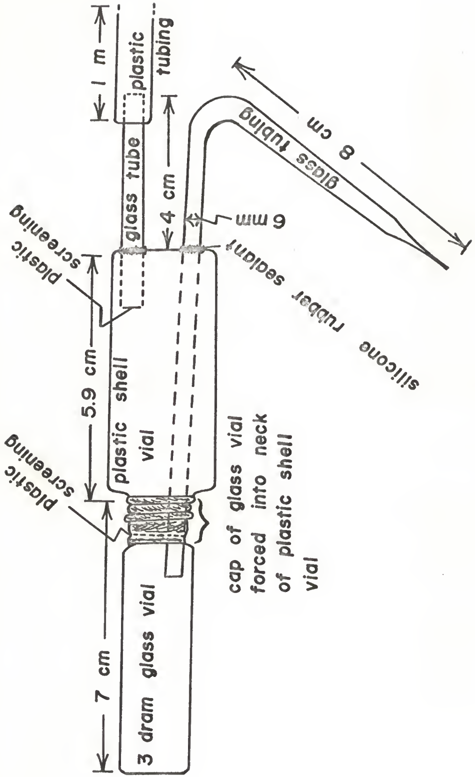
(3) number of weevil feeding spots and eggs;

(4) number of waterhyacinth mite oviposition holes; and

(5) number of waterhyacinth mite tunnels.

In order to collect the large number of mites needed for these experiments (more than 2000/week), a new technique was developed. At first, waterhyacinth mite adults were collected with a camel's hair brush. This method of collecting individual waterhyacinth mites

Figure 13.— Schematic view of mite aspirator used to collect adult Orthogalumna terebrantis Wallwork from waterhyacinth in the field.


1 m
plastic tubing
glass tube
4 cm
8 cm
glass tubing
6 mm
silicone rubber sealant
plastic screening
5.9 cm
plastic shell vial
plastic screening
cap of glass vial forced into neck of plastic shell vial
7 cm
3 dram glass vial

required several hours and was extremely tedious. A new mite aspirator was developed (Figure 13) which allowed collection in the field of several thousand adult waterhyacinth mites/hour (depending on the number of mites present). With this aspirator, it was a simple matter to collect only the adult galumnid mites needed, and pass over other mites.

Incubator 1, with the lowest temperature regime, was unreliable for all experiments. Plant material, nutrient solution and water froze within 1 week. For this reason, experiments in incubator 1 were terminated after 3 weeks.

Results and Discussion

No detrimental effect on weevil oviposition was noted aver a 10-week period (Table 32). Number of eggs laid/female was higher in incubators 2 (for all levels of mites) and 3 (for 50 mites/pseudolamina) when mites were present as compared to controls without mites.

Extrapolating these results to the field, there may be no detrimental effect of large populations of adult waterhyacinth mites on mottled waterhyacinth weevil oviposition. In fact, weevils may even oviposit more when populations of mites are high (see p. 110).

EFFECT OF ADULT WATERHYACINTH MITES ON WEEVIL EGGS

Methods and Materials

Using the Freas incubators at the settings described above, 3 freshly collected eggs of the mottled waterhyacinth weevil and 10 adult waterhyacinth mites were placed on dampened filter paper in petri dishes sealed with silicone grease. This was done to determine if mites would feed on weevil eggs under starvation conditions. One such petri dish was added to each incubator weekly. Controls without mites were added after the third week.

Results and Discussion

In 10 weeks of testing, there was no feeding or attempt to feed on mottled waterhyacinth weevil eggs by adult waterhyacinth mites. This was revealed after careful microscopic examination of eggs. Controls remained in good condition each week. Mites starved in the presence of weevil eggs as their only source of food.

Whether these data, collected under highly artificial conditions in incubators, can be extrapolated to field occurrences under similar conditions is not known. However, since mites in all incubators (representing 4 different temperature regimes) starved rather than fed upon weevil eggs, the conclusion that weevil eggs will not be attacked heavily by waterhyacinth mite adults in the field is probably valid.

TEMPERATURE AND HUMIDITY OPTIMA: EFFECT OF ABIOTIC FACTORS

Methods and Materials

Using the Freas chambers at the settings described above, 5 pairs (5 females: 5 males) of adult mottled waterhyacinth weevils were added to 1 weighed and measured waterhyacinth plant. Another similarly prepared plant was infested with 50 adult waterhyacinth mites. Plants were placed in 2.5 liter stainless steel jars containing 2 liters of 0.5% Hoagland's nutrient colution and ringed with silicone grease to prevent escape of mites. A similar unit was placed in each of the incubators.

Each week, for 2-weeks, data were taken on number of adult weevils and mites/plant and age and number/cm^2 of feeding spots and tunnels. Within this period, however, all plants were destroyed by the arthropods, so an alternate design had to be conceived.

Oviposition of mites and weevils (described under "Effect of Adult Waterhyacinth Mites on Weevil Oviposition") was used as an index of growth of mite and weevil populations, respectively. In addition, adult waterhyacinth mites were added to pie pans prepared as in "Effect of Adult Waterhyacinth Mites on Weevil Oviposition," above, except that no silicone grease was used. Additional pie pans were prepared with the silicone grease layer, in which was placed a healthy waterhyacinth pseudolamina inserted in a water-filled test tube. The pseudolaminae (which were collected in the

greenhouse at the USDA station in Davie) contained approximately 200-500 immature mite tunnels. One of each set of pie pans was placed in each incubator. Data on number of eggs laid at each temperature regime, plus number of adult mites which emerged from the tunnels were taken for 10 weeks.

Similar abiotic data were taken for field experiments. Numbers of weevils and mites/plant were determined for the duration of the study. Periodically the number of weevil larvae (based on number of larval tunnels/plant) and number of pupae/plant were determined along with immature waterhyacinth mites.

Results and Discussion

Humidity measurements in the incubators were too sporadic for any definite conclusions to be reached on optima for mite or weevil development. High RH, however, seemed to favor development of both species (Table 32) because incubators 2 and 3, which had best development of arthropods, also had highest RH.

High and low extremes of temperature were most unfavorable to development of both species (Table 32), with mottled waterhyacinth weevil mortality being 100% at the low temperature regime (5-25°C) and 15-43% at the high temperature regime (20-40°C), and 100% for adult waterhyacinth mites at both extreme regimes.

Weevils laid twice as many eggs (125) at temperature regime 3 (15-35°C) as compared with temperature regime 2 (10-30°C) (63)

(Table 32). Number of eggs laid by weevils was affected by number of mites present; at temperature regime 2, 41% were laid at the lower 2 levels of mites, and 56% at the higher 2 levels of mites (with only 3% laid by control weevils). At temperature regime 3, 39% of the eggs were laid at the lower 2 levels of mites, 35% at the higher 2 levels, and 26% by control weevils.

Mite tunnels produced at the different temperature regimes were also affected by temperature (Table 32). As with weevil oviposition, the 2 extreme regimes were most unsuitable for mite development, with no tunnels produced at the lower regime, and an average of 0.096 tunnels/female/week at the higher regime. Temperature regime 2 was also most favorable for mite tunnel development, with a total of 1061 emerged adults as compared with 731 at temperature regime 3.

Mite oviposition and development showed a similar trend (Table 33). Most eggs were laid at temperature regimes 4 (599) and 3 (598), followed by 2 (529) and 1 (6). There was no statistical difference, however, between number of eggs laid/female in incubators 2, 3 or 4 (based on assumptions of a 1:1 sex ratio and 25 females/pan), with averages of 21.16, 23.92 and 23.96 eggs/female, respectively.

Number of nymphs and larvae developing to adults in the incubators showed the reverse correlation, with the greatest per cent developing at temperature regime 2, followed by 3, 4 and 1, respectively. Average per cent developed from these temperature regimes were 43.2, 22.8, 18.4 and 4.2, respectively (Table 33).

These data generally correspond to known temperature tolerances of mottled waterhyacinth weevils in the field. Mite data also correspond to best development in the field; i.e. approximately 30°C.

WATER CHEMISTRY, NUTRIENTS
AND ELEMENTAL COMPOSITION OF WATERHYACINTH

Methods and Materials

Measurements of alkalinity (total, hydroxide and carbonate), NaCl, $CaCO_3$ color, Cu. $MgCO_3$, total hardness, NO_3, DO, water temperature, pH, PO_4 (available and total) and turbidity were made on water from the release site, from ponds which supplied coffin-holders, and from coffin-holders. All samples, except those from ponds (which are sampled monthly for other tests), were collected after week 50.

At the release site of N. eichhorniae, water samples were taken at a depth of approximately 40 cm (root level) at points A, B and C (Figure 1) for all measurements except DO and water temperature, which were taken at a depth of 0 (surface), 40 (root level) and approximately 100 cm (bottom) at all 10 areas. DO and water temperature were taken with a Yellow Springs Instrument Company® Model 51A Oxygen Meter. All other analyses were run according to instructions in Standard Methods (1971).

Plants were collected prior to testing and after 50-weeks. Both wet and dry weights were taken on all collected plants from areas 1-10 at the field release site and from coffin-holders. After taking meristic data on week 50 in both areas, 1 plant each from areas 1-10 was placed in a 25-gallon plastic bag and sealed to prevent escape of contained biota. A similar method was used to contain coffin-holder plants. Plants from each study were then

placed individually into Berlesè funnels and dried for 1 week with 25-watt incandescent bulbs. Biota were heat-extracted into 70% ethyl alcohol. Plants were then removed from the Berlesè funnels and further dried in a forced-air drying oven for 2-weeks at 21.1°C. Plants were then ground up in a Thomas-Wiley Laboratory Mill® Model 4, and redried for 7 days in a Precision-Thelco® forced-air drying oven Model 6 at 25°C. Analyses of N, P, K and crude protein were then run on all plants as per instructions in Standard Methods (1971). Plant material was weighed for analyses with Mettler® Models H10 and P1200 single pan balances.

Results and Discussion

Water quality measurements were significantly different between canal and coffin-holder areas (Tables 34 and 35, respectively) for all parameters. Canal parameters were consistently higher than coffin-holder parameters for all measurements save pH, which was generally slightly higher in the coffin-holders.

Levels of all nutrients exceeded those needed for growth of waterhyacinth, so nutrients were not considered to be limiting in either study. This is critical to valid interpretation of the stress applied by biological control agents; if plants were stressed by lack of a critical nutrient, then effect of released phytophagous arthropods would not be accurately gauged.

Since all coffin-holders had the same nutrients added (i.e. pond water and 0.5% Hoagland's nutrient solution) in exactly the same smounts, the amount of these nutrients present in the water would be an inverse function of the absorption by waterhyacinth.

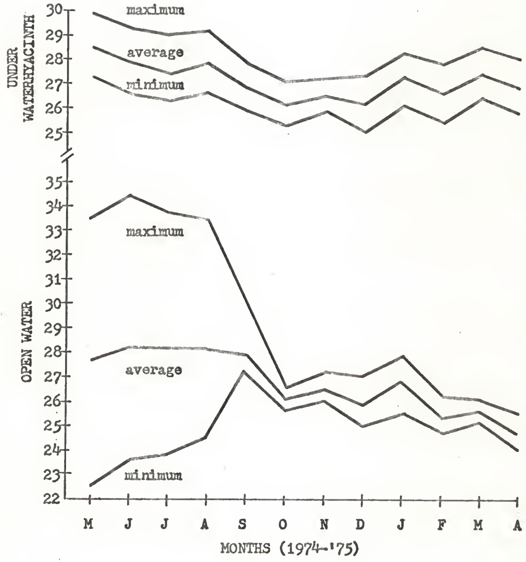
Water in coffin-holders containing weevil-mite combinations (released simultaneously) had the lowest amounts of nutrients in most cases (Table 35), and controls had generally the highest amount of nutrients in the water. Stressing waterhyacinth, then, causes it to take up more nutrients that it would if not stressed by arthropods.

These results are also reflected by elemental content data of waterhyacinth from each treatment (Table 36). Plants containing simultaneously-applied weevils and mites had the highest content of N and crude protein (CP), and very high P and K, when compared to other treatments. Other authors have obtained results from elemental analyses of aquatic plants (Gerloff et al. 1964, Reimer and Toth 1968) and waterhyacinth that were not stressed by arthropods (Table 37). These unstressed plants had an average of N, P, K and CP higher than plants in my experiments. Even taking different areas and times of sampling into consideration, these results may indicate that nutrient removal capabilities of these and other biotic agents can be significant.

Plants from the release canal, however, had higher levels of these nutrients than did plants from coffin-holders (Table 36). Water from the canal, however, had much higher nutrients levels than did pond or coffin-holder water, which may account for this difference (Tables 34 and 35).

DO readings were the reverse of nutrient-content data (Table 38). Both temperature and DO were higher in coffin-holders than the field. In both cases, however, DO was very low under waterhyacinth, and could certainly inhibit aquatic life in these situations. Temperatures under waterhyacinth and in open water contained in coffin-holders showed similar trends to field water temperatures (Figure 14). Temperatures were more constant and extremes were less under waterhyacinth than open water.

Figure 14.— Monthly changes in water temperature (^{o}C) in coffin-holders in Davie, Florida.



UNDER WATERHYACINTH
OPEN WATER
maximum
average
minimum
maximum
average
minimum
30
29
28
27
26
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35
34
33
32
31
30
29
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27
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A
MONTHS (1974-'75)

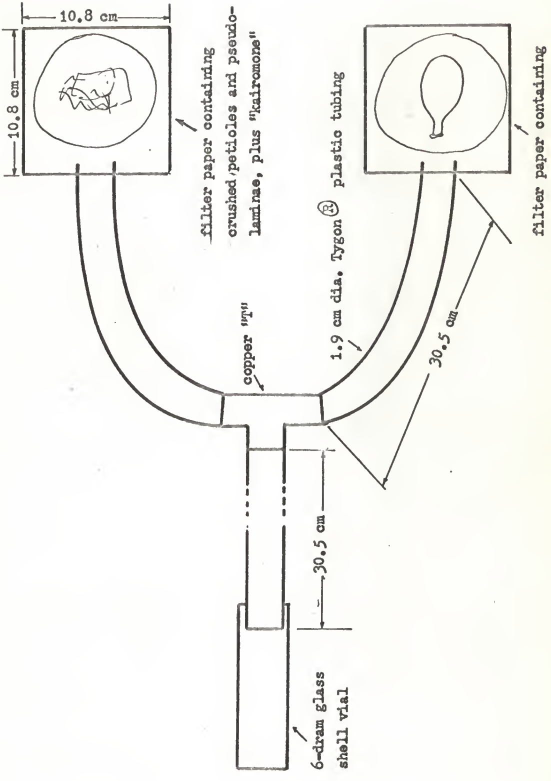
DISCOVERY OF A POSSIBLE KAIROMONE FROM WATERHYACINTH

Methods and Materials

An insect olfactometer was designed (Figure 15) to test the attraction of N. eichhorniae to a chemical produced by growing waterhyacinth pseudolaminae and petioles. This chemical (or complex of chemicals) may be a kairomone, because it attracts phytophagous organisms which feed on waterhyacinth. (A kairomone can be defined generally as a semiochemical produced by one organism which attracts members of another species, which then damages the producing species in some way; i.e. a chemical message that does not benefit the producing organism.) This "kairomone" is also suspected of being the phagostumulant for mottled waterhyacinth weevils and waterhyacinth mite adults, and may cause adult weevils to oviposit more heavily when present in high amounts (see "Contributions to the Theory of Biological Control of Aquatic Macrophytes with Primary Consumers," p. 107.)

Crushed waterhyacinth petioles and ground pseudolaminae were added to the left-hand plastic box in Figure 15. A whole, mature pseudolamina (with its cut end sealed to prevent escape of the "kairomone") was added to the right box. Twenty-seven adult Neochetina spp. were added to the shell vial, and left overnight. The experiment was replicated 3 more times, alternating the samples each time. No air flow was maintained through the olfactometer. Number of weevils in each box after 24, 36 and 48 hours was noted.

Figure 15.— Schematic view of olfactometer designed to test attraction of _Neochetina eichhorniae_ Warner to waterhyacinth petioles and pseudolaminae containing a possible "kairomone."


10.8 cm
10.8 cm
filter paper containing crushed petioles and pseudo-laminae, plus "kairomone"
filter paper containing pseudolamina.
1.9 cm dia. Tygon® plastic tubing
copper "T"
30.5 cm
30.5 cm
6-dram glass shell vial

Results and Discussion

After 24 hours, over 90% of the insects were attracted to the left chamber (or the chamber containing the "kairomone" in later replications) of the olfactometer. The existance of a chemical that attracts weevils to broken and crushed plants is thus confirmed. These weevils also created more feeding spots/insect than those attracted to whole pseudolaminae with sealed ends, so a phagostimulant is probably also involved.

It has already been shown that mottled waterhyacinth weevils lay more eggs in the presence of mites (Table 32). This may be due to release of more of this "kairomone" by the addition of mite damage.

Thus, not only are weevils tied to waterhyacinth in their pupal stage (due to the needed root hairs for pupation), but they may also be stimulated to lay more eggs, feed more, and aggregate around injured plants due to a "kairomone" chemical (or complex of chemicals) present in waterhyacinth tissue.

CONTRIBUTIONS TO THE THEORY OF

BIOLOGICAL CONTROL OF AQUATIC MACROPHYTES WITH PRIMARY CONSUMERS

Results of these experiments may add to our knowledge of biological control of aquatic weeds with obligatorily monophagous (or stenophagous) primary consumers. There is a very complex relationship between introduced herbivores, their host plants and the environment. Although biological control of terrestrial weeds has been discussed extensively (Huffaker 1959, 1964, Huffaker and Kennett 1959, Wilson 1964, Zwölfer 1973, Zwölfer and Harris 1971), literature and demonstrated examples of biological control of aquatic macrophytes are scarce (Andres and Bennett 1975, Zeiger 1967, Hawkes et al. 1967).

Floating hydrophytes are under a great deal of stress from the environment. Terrestrial weeds are subject to fluctuations of the environment; submerged aquatics are generally under more constant conditions, due to the influence of their surrounding aqueous medium; but floating aquatic plants must have mechanisms by which they can thrive in both media at the same time.

Eradication of an aquatic weed is rarely, if ever, the desired end point in a biological control program. Phytophagous arthropods are usually introduced to reduce size and/or density of plants to some anthropocentrically determined allowable level. This level is a highly arbitrary figure and varies depending upon local conditions. Conflict of interest is obviously intimately involved in this process of determination of allowable level. A hypothetical goal, namely a fringe of waterhyacinth on a given body of water, may not be attainable with only 1 or 2 biological control agents, even if releases of exotic arthropods are backed up by sound biological and

ecological data.

It has been demonstrated herein that release of N. eichhorniae on a mat of waterhyacinth that is infested with O. terebrantis can reduce size and density of waterhyacinth significantly over the period of 1 year, under certain conditions. This reduction has not reached the extent of limiting growth of waterhyacinth to a fringe of plants as yet. Nor has this goal been reached in areas of Ft. Lauderdale where weevils have been established for over 3½ years (Perkins, pers. comm.) and mites for perhaps 70 or more years. The reduction that has been realized in these experiments has coincided with increase in populations of the mottled waterhyacinth weevil, and has been aided by high populations of waterhyacinth mites with the concomitant heavy invasion by pathogenic fungi and saprophytes. These effects should theoretically increase with the addition of the second species of Argentine weevil, N. bruchi, which is presently in the field in Ft. Lauderdale.

Unlike biological control of insects, then (where the main stress is exerted by the released biological control agent(s) itself), biological control of waterhyacinth in the United States may follow a different pattern. The release of waterhyacinth weevils (and other direct pseudolaminae and petiole feeders such as grasshoppers, which are slated for future release) exerts a certain amount of direct stress by destruction of photosynthetic tissue. Weevils, based on results of experiments described herein, lay more eggs in the presence of mites. Reasons for this were at first obscure,

but may involve the following mechanism. It has recently been found (Perkins and Lovarco, pers. comm.) that breaking petioles of a waterhyacinth plant causes an 8-16-fold increase in the number of weevils that come on to a plant. Results of the olfactometer experiment (p. 106) have shown that a possible "kairomone" is released from the young, growing petiolar tissue in the breaking process, which draws insects to the point of breakage. Such a stimulant may also stimulate weevils to increase oviposition.

Extrapolating these concepts to the field situation where great numbers of waterhyacinth mites are present leads to the following proposed hypothesis of interaction of weevils, mites and plants. When adult mottled waterhyacinth weevils are first released in an area, most of their feeding is concentrated around a very small area. When adult weevils are present, their feeding creates feeding sites for adult waterhyacinth mites. Since waterhyacinth mites can easily feed on pseudolaminae with breaks in the tissues (Del Fosse et al. 1975), a favorable habitat for waterhyacinth mite development is thus created. As waterhyacinth mites begin to oviposit, more of this "kairomone" in pseudolaminae is released. This in turn attracts more weevils to plants, which may be stimulated by the "kairomone" (or part of the chemical complex) to oviposit more. This leads to more suitable feeding sites for adult water-hyacinth mite feeding, and the process continues, limited mainly by ambient abiotic conditions (which limit growth of waterhyacinth mite populations). This also explains the synergistic effect of the

populations of waterhyacinth weevils and mites when they are in combination on plants, and the limited dispersion of weevils for months after initial release of adult weevils.

The double stress thusly applied to infested waterhyacinth plants by the synergistic combination of waterhyacinth weevils and mites is further multiplied by the addition of pathogenic fungi. As earlier demonstrated, there is a very close relationship between incidence of _A. zonatum_, the causal agent of zonate leaf spot disease of waterhyacinth, and mite tunnels of age 4; i.e. after the adult mite has created its emergence hole. Since adult waterhyacinth mites are attracted to fresh weevil feeding spots (i.e. age 1), and adult weevils are stimulated to lay more eggs and feed more heavily when large numbers of waterhyacinth mites are present (possibly due to the increased titre of "kairomone" released by waterhyacinth mite feeding), which will lead to heavier mite populations, the amount of fungus (or other waterhyacinth mite-dependent pathogens) may be directly related to the interaction of these 2 arthropods.

Thus, the interaction between _N. eichhorniae_ and _O. terebrantis_ is a very complex one, but all indications point to cooperation rather than disoperation, which leads to a synergistic effect on waterhyacinth.

APPENDIX

Table 1.— Monthly averages of *Neochetina eichhorniae* Warner (NE) and *Orthogalumna terebrantis* Wallwork (OT) populations and damage data after NE release on an OT-infested mat of waterhyacinth. Values are averages of 4 samples each from Area 1. Values in the same column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Date	Adult OT/Plant	OT Tunnels Age	OT Tunnels No./cm^2	ODI[a]	Adult NE/Plant	NE Feeding Spots Age	NE Feeding Spots No./cm^2	NDI[b]
18 VI 1974	150.00 a–c	2.00 a	12.00 a,b	24.00 a	0.00 a	1.00 a	5.00 a	20.00 a
09 VII	212.50 a–c	2.62 a	10.00 a,b	26.20 a	0.00 a	2.75 b–d	4.75 a	10.69 a
06 VIII	52.75 a	3.00 a	8.50 a	25.50 a	0.25 a	1.88 a,b	7.25 a–c	22.62 a
03 IX	186.50 a–c	2.75 a	11.00 a,b	30.25 a	0.25 a	2.88 b–d	5.50 a,b	11.66 a
01 X	378.50 c	2.50 a	12.50 a,b	31.25 a	2.75 a,b	2.62 b–d	8.50 b,c	20.23 a
29 X	801.50 d	1.75 a	15.75 b	27.56 a	4.75 b	2.25 b,c	7.00 a–c	19.25 a
26 XI	245.20 a–c	2.50 a	8.00 a	20.00 a	2.00 a,b	2.75 b–d	7.50 a–c	16.88 a
24 XII	336.50 b,c	1.75 a	5.75 a	10.06 a	1.00 a,b	2.38 b,c	7.25 a–c	19.00 a
27 I 1975	230.50 a–c	2.25 a	11.75 a,b	26.44 a	2.50 a,b	3.38 c,d	7.50 a–c	12.15 a
18 II	277.75 a–c	2.50 a	12.00 a,b	30.00 a	2.00 a,b	2.88 b–d	9.00 c	19.08 a
18 III	122.75 a,c	1.75 a	8.50 a	14.88 a	2.75 a,b	3.50 c,d	8.25 b,c	12.38 a
15 IV	171.50 a–c	2.38 a	6.75 a	16.06 a	1.50 a,b	3.88 d	10.00 c	11.20 a
13 V	44.25 a	2.25 a	10.25 a,b	23.06 a	2.00 a,b	3.12 b–d	9.50 c	17.86 a
27 V	82.00 a,b	1.25 a	10.00 a,b	12.50 a	3.00 a,b	2.75 b–d	10.00 c	22.50 a

[a] ODI= (age of OT tunnels)(no./cm^2).

[b] NDI= [5 – (age of NE feeding spots)](no./cm^2).

Table 2.— Monthly averages of _Neochetina eichhorniae_ Warner (NE) and _Orthogalumna terebrantis_ Wallwork (OT) populations and damage data after NE release on an OT-infested mat of waterhyacinth. Values are averages of 4 samples each from Area 2. Values in the same column fllowed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Date	Adult OT/Plant	OT Tunnels Age	OT Tunnels No./cm^2	ODI[a]	Adult NE/Plant	NE Feeding Spots Age	NE Feeding Spots No./cm^2	NDI[b]
18 VI 1974	114.00 a	3.00 a	14.00 b,c	42.00 b	3.00 a,b	1.00 a	9.00 b	36.00 b
09 VII	131.25 a	3.25 a	9.75 a,b	31.69 a,b	1.00 a,b	2.12 a,b	8.00 a,b	23.04 a,b
06 VIII	91.50 a	2.75 a	10.00 a,b	27.50 a,b	0.50 a,b	2.50 b,c	7.50 a,b	18.75 a
03 IX	314.50 a,b	2.75 a	12.00 a–c	33.00 a,b	0.00 a	2.38 b,c	5.00 a	13.10 a
01 X	699.25 c	2.12 a	14.25 b,c	30.21 a,b	1.75 a,b	2.50 b,c	7.25 a,b	18.12 a
29 X	1393.00 d	2.25 a	17.25 c	38.81 a,b	3.50 a,b	2.62 b,c	7.75 a,b	18.44 a
26 XI	451.75 b,c	1.88 a	12.50 b,c	23.50 a,b	2.00 a,b	2.62 b,c	8.25 b	19.64 a
24 XII	271.75 a,b	1.75 a	8.00 a,b	14.00 a,b	3.25 a,b	2.62 b,c	6.75 a,b	16.06 a
27 I 1975	289.75 a,b	1.75 a	11.25 a–c	19.69 a,b	2.00 a,b	3.62 b,c	7.50 a,b	10.35 a
18 II	183.00 a,b	2.12 a	10.25 a,b	21.73 a,b	3.00 a,b	3.00 b,c	8.25 b	16.50 a
18 III	63.00 a	2.12 a	11.50 a–c	24.38 a,b	2.25 a,b	3.62 c	7.00 a,b	9.66 a
15 IV	339.25 a,b	2.12 a	5.50 a	11.66 a	1.50 a,b	2.88 b,c	9.00 b	19.08 a
13 V	112.25 a	2.38 a	9.50 a,b	22.61 a,b	4.75 b	2.75 b,c	9.25 b	20.81 a
27 V	62.50 a	2.25 a	8.50 a,b	19.12 a,b	3.50 a,b	2.75 b,c	9.50 b	21.38 a, b

[a] ODI= (age of OT tunnels)(no./cm^2).

[b] NDI= $[5$ - (age of NE feeding spots)$]$(no/cm^2).

Table 3.— Monthly averages of Neochetina eichhorniae Warner (NE) and Orthogalumna terebrantis Wallwork (OT) populations and damage data after NE release on an OT-infested mat of waterhyacinth. Values are averages of 4 samples each from Area 3. Values in the same column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Date	Adult OT/Plant	OT Tunnels		ODI[a]	Adult E/Plant	NE Feeding Spots		NDI[b]
		Age	No./cm^2			Age	No./cm^2	
18 VI 1974	81.90 a,b	2.00 a	18.00 d	36.00 b-e	0.00 a	0.00 a	0.00 a	0.00 a
09 VII	106.25 a,b	3.00 a	17.00 d	51.00 e	0.00 a	1.88 b	3.25 b	10.14 a,b
06 VIII	50.50 a,b	2.62 a	13.50 b-d	35.37 b-e	0.00 a	2.12 b	5.75 d-d	16.56 b,c
03 IX	404.75 c,d	2.12 a	15.25 c,d	32.33 a-e	0.00 a	2.00 b	5.50 b,c	16.50 b,c
01 X	1270.00 f	2.38 a	18.50 d	44.03 c-e	1.00 a	2.50 b,c	7.00 c-e	17.50 b,c
29 X	822.75 e	1.75 a	16.25 d	28.44 a-e	2.00 a	2.62 b,c	7.25 c-e	17.26 b,c
26 XI	491.75 d	1.25 a	9.25 a-c	11.56 a,b	3.25 a	2.75 b,c	8.50 c-e	19.12 b,c
24 XII	327.25 b-d	1.75 a	9.25 a-c	16.19 a-d	3.00 a	2.88 b,c	9.00 e	19.08 b,c
27 I 1975	208.00 a-c	1.88 a	13.25 b-d	24.91 a-e	0.50 a	3.12 b,c	8.75 d,e	16.45 b,c
18 II	275.25 a-d	1.88 a	8.25 a,b	15.47 a-c	2.75 a	3.75 c	8.75 d,e	10.94 a,b
18 III	35.50 a	3.12 a	14.50 b-d	45.24 d,e	0.25 a	3.12 b,c	8.75 d,e	16.45 b,c
15 IV	156.50 a-c	1.12 a	3.75 a	4.22 a	4.00 a	3.00 b,c	9.25 e	18.50 b,c
13 V	51.25 a,b	2.75 a	13.25 b-d	36.44 b-e	3.25 a	2.38 b	9.50 e	24.89 c
27 V	166.00 a-c	2.25 a	8.00 a,b	18.00 a-d	3.00 a	3.25 b,c	8.00 c-e	14.00 b,c

[a] ODI= (age of OT tunnels)(no./cm^2).

[b] NDI= [5 - (age of NE feeding spots)](no./cm^2).

Table 4.— Monthly averages of *Neochetina eichhorniae* Warner (NE) and *Orthogalumna terebrantis* Wallwork (OT) populations and damage data after NE release on an OT-infested mat of waterhyacinth. Values are averages of 4 samples each from Area 4. Values in the same column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Date	Adult OT/Plant	OT Tunnels		ODI[a]	Adult NE/Plant	NE Feeding Spots		NDI[b]
		Age	No./cm^2			Age	No./cm^2	
18 VI 1974	49.00 a	2.00 a	14.00 b-d	28.00 a,b	3.00 a	1.00 a	3.00 a	12.00 a
09 VII	84.25 a	2.62 a	14.75 b-d	38.64 a,b	0.75 a	3.00 b,c	6.50 b-d	13.00 a
06 VIII	58.50 a	2.88 a	10.00 a-c	28.80 a,b	0.00 a	2.00 a,b	4.00 a,b	12.00 a
03 IX	221.75 a,b	2.25 a	13.00 a-d	29.25 a,b	0.25 a	2.50 b,c	5.25 a-c	13.12 a
01 X	438.75 b	2.50 a	19.00 d	47.50 b	1.50 a	2.50 b,c	6.75 b-d	16.88 a
29 X	881.75 c	2.38 a	16.00 c,d	38.08 a,b	2.50 a	2.25 b,c	6.50 b-d	17.88 a
26 XI	1056.25 d	2.00 a	9.75 a-c	19.50 a,b	5.00 a	2.50 b,c	8.75 d	21.88 a
24 XII	270.50 a,b	1.00 a	11.00 a-c	11.00 a	4.25 a	2.50 b,c	7.00 b-d	17.50 a
27 I 1975	155.00 a	1.25 a	12.75 a-d	15.94 a	2.25 a	3.12 b,c	9.25 d	17.39 a
18 II	323.50 a,b	2.25 a	13.00 a-d	29.25 a,b	2.00 a	3.38 c	9.25 d	14.99 a
18 III	66.50 a	2.12 a	8.00 a,b	16.96 a	2.00 a	3.38 a	6.50 b-d	10.53 a
15 IV	80.75 a	2.25 a	7.00 a	15.75 a	3.50 a	3.00 b,c	8.75 d	17.50 a
13 V	53.75 a	1.75 a	14.25 b-d	24.94 a,b	3.50 a	2.75 b,c	8.25 c,d	18.56 a
27 V	163.00 a	2.50 a	15.50 b-d	38.75 a,b	5.50 a	3.50 c	10.00 d	15.00 a

[a] ODI= (age of OT tunnels)(no./cm^2).

[b] NDI= [5 - (age of NE feeding spots)](no./cm^2)

Table 5.— Monthly averages of *Neochetina eichhorniae* Warner (NE) and *Orthogalumna terebrantis* Wallwork (OT) populations and damage data after NE release on an OT-infested mat of waterhyacinth. Values are averages of 4 samples each from Area 5. Values in the same column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Date	Adult OT/Plant	OT Tunnels Age	OT Tunnels No./cm^2	ODI[a]	Adult NE/Plant	NE Feeding Spots Age	NE Feeding Spots No./cm^2	NDI[b]
18 VI 1974	90.00 a	3.00 a	13.00 a-c	39.00 a-c	0.00 a	1.00 a	7.00 a-d	28.00 b
09 VII	103.50 a	3.75 a	16.00 b,c	60.00 c	0.00 a	2.25 b,c	4.00 a	11.00 a
06 VIII	81.50 a	3.25 a	9.75 a,b	31.69 a-c	0.50 a	1.88 a,b	4.50 b	14.04 a
03 IX	284.75 a-c	2.62 a	11.50 a-c	30.13 a,b	1.00 a	2.25 b,c	6.25 a-c	17.19 a,b
01 X	490.25 b,c	2.88 a	17.75 c	51.12 b,c	1.50 a,b	2.62 b-d	6.50 a-d	15.47 a,b
29 X	416.25 b,c	2.12 a	16.25 b,c	34.45 a-c	2.25 a,b	2.75 b-d	6.75 a-d	15.19 a,b
26 XI	555.00 c	2.38 a	15.75 b,c	37.48 a-c	2.75 a,b	3.12 b-d	7.25 b-d	13.63 a
24 XII	270.00 a,b	1.75 a	14.25 a-c	24.94 a,b	3.25 1,b	2.62 b-d	8.00 c,d	19.04 a,b
27 I 1975	129.75 a	1.75 a	12.00 a-c	21.00 a	4.25 a,b	3.88 d	8.25 c,d	9.24 a
18 II	223.00 a,b	1.75 a	8.75 a	15.31 a	0.25 a	3.38 c,d	8.00 c,d	12.96 a
18 III	90.00 a	1.62 a	7.50 a	12.15 a	5.75 b	3.88 d	8.00 c,d	8.96 a
15 IV	95.50 a	2.38 a	7.50 a	17.85 a	4.00 a,b	3.88 d	9.00 c,d	10.08 a
13 V	61.25 a	2.12 a	11.25 a-c	23.85 a,b	1.75 a,b	3.62 d	9.50 d	13.11 a
27 V	320.00 a-c	1.75 a	11.00 a-c	19.25 a	1.50 a,b	3.00 b-d	8.50 c,d	17.00 a,b

[a] ODI= (age of OT tunnels)(no./cm^2).

[b] NDI= [5 - (age of NE feeding spots)](no./cm^2).

Table 6.— Monthly averages of Neochetina eichhorniae Warner (NE) and Orthogalumna terebrantis Wallwork (OT) populations and damage data after NE release on an OT-infested mat of waterhyacinth. Values are averages of 4 samples each from Area 6. Values in the same column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Date	Adult OT/Plant	OT Tunnels		ODI[a]	Adult NE/Plant	NE Feeding Spots		NDI[b]
		Age	No./cm^2			Age	No./cm^2	
18 VI 1974	35.00 a	3.00 a	20.00 e	60.00 d	0.00 a	1.00 a	6.00 a	24.00 b,c
09 VII	57.00 a	3.38 a	12.75 a-d	43.10 b-d	0.00 a	2.75 b-d	5.75 a	12.94 a,b
06 VIII	87.75 a	2.38 a	9.75 a-c	23.20 a,b	0.25 a	2.25 b,c	6.00 a,b	16.50 a,b
03 IX	118.75 a	2.25 a	12.50 a-c	28.12 a-c	2.25 a,b	1.50 a,b	7.00 a-c	24.50 b,c
01 X	496.50 b	2.12 a	13.75 b-e	29.15 a-c	5.00 b,c	2.50 b,c	7.75 a-c	19.38 a-c
29 X	805.75 c	3.00 a	18.00 d,e	54.00 c,d	3.50 a-c	2.88 c,d	8.75 a-c	18.55 a-c
26 XI	533.00 b	2.12 a	10.75 a-c	22.79 a,b	7.00 c	3.12 c,d	8.75 a-c	16.45 a,b
24 XII	194.75 a	2.12 a	12.50 a-c	26.50 a-c	3.25 a-c	3.25 c,d	9.00 b,c	15.75 a,b
27 I 1975	129.50 a	2.62 a	8.50 a,b	22.27 a,b	2.75 a,b	4.00 d	9.25 c	9.25 a
18 II	174.00 a	2.25 a	11.00 a-c	24.75 a,b	1.75 a,b	2.88 c,d	9.25 c	19.61 a-c
18 III	42.25 a	2.00 a	6.00 a	12.00 a	2.75 a,b	3.50 c,d	9.50 c	14.25 a,b
15 IV	128.50 a	3.00 a	8.50 a,b	25.50 a-c	0.50 a	2.50 b,c	8.00 a-c	20.00 a-c
13 V	38.25 a	1.62 a	12.75 a-d	20.66 a,b	3.25 a-c	1.62 a,b	9.25 c	31.26 c
27 V	58.50 a	2.75 a	15.50 c-e	42.62 b-d	0.50 a	3.00 c,d	9.00 b,c	18.00 a-c

[a] ODI= (age of OT tunnels)(no./cm^2).

[b] NDI= [5 - (age of NE feeding spots)](no./cm^2).

Table 7.— Monthly averages of *Neochetina eichhorniae* Warner (NE) and *Orthogalumna terebrantis* Wallwork (OT) populations and damage data after NE release on an OT-infested mat of waterhyacinth. Values are averages of 4 samples each from Area 7. Values in the same column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Date	Adult OT/Plant	OT Tunnels		ODI[a]	Adult NE/Plant	NE Feeding Spots		NDI[b]
		Age	No./cm^2			Age	No./cm^2	
18 VI 1974	21.00 a	2.00 a	13.00 b,c	26.00 a,b	0.00 a	1.00 a	4.00 a	16.00 a
09 VII	39.50 a	2.88 a	14.75 b,c	42.48 b	0.00 a	1.75 a,b	3.75 a	12.19 a
06 VIII	17.50 a	3.25 a	10.75 a-c	34.94 a,b	0.00 a	2.12 a-c	6.50 a,b	18.72 a
03 IX	199.50 a,b	2.12 a	9.75 a-c	20.67 a,b	0.75 a,b	2.62 b-e	7.75 b,c	18.44 a
01 X	586.50 c	2.00 a	16.50 c	33.00 a,b	1.25 a,b	2.75 b-e	7.25 b,c	16.32 a
29 X	1432.00 d	2.25 a	15.00 b,c	33.75 a,b	4.00 a,b	2.38 b-d	9.50 b,c	24.89 a
26 XI	544.25 c	2.88 a	15.25 b,c	43.92 b	4.25 a,b	3.75 e	9.50 b,c	11.88 a
24 XII	236.75 a,b	1.75 a	5.50 a	9.62 a	2.25 a,b	3.50 d,e	8.25 b,c	12.38 a
27 I 1975	370.75 b,c	2.62 a	11.75 a-c	30.78 a,b	2.00 a,b	3.75 e	9.75 c	12.19 a
18 II	396.25 b,c	2.25 a	10.25 a-c	23.06 a,b	4.00 a,b	3.75 e	10.00 c	12.50 a
18 III	160.75 a,b	1.88 a	9.00 a,b	16.92 a,b	2.00 a,b	2.88 b-e	8.00 b,c	16.96 a
15 IV	134.25 a,b	2.88 a	9.50 a,b	27.36 a,b	1.75 a,b	3.00 b-e	8.00 b,c	16.00 a
13 V	120.25 a,b	2.25 a	14.50 b,c	32.62 a,b	0.25 a,b	3.00 b-e	9.75 c	19.50 a
27 V	160.00 a,b	2.75 a	11.50 a-c	31.62 a,b	4.50 b	3.25 c-e	7.50 b,c	13.12 a

[a]ODI= (age of OT tunnels)(no./cm^2).

[b]NDI= [5 - (age of NE feeding spots)](no./cm^2).

Table 8.— Monthly averages of <u>Neochetina eichhorniae</u> Warner (NE) and <u>Orthogalumna terebrantis</u> Wallwork (OT) populations and damage data after NE release on an OT-infested mat of waterhyacinth. Values are averages of 4 samples each from Area 8. Values in the same column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Date	Adult OT/Plant	OT Tunnels		ODI[a]	Adult NE/Plant	NE Feeding Spots		NDI[b]
		Age	No./cm^2			Age	No./cm^2	
18 VI 1974	35.00 a	3.00 a	11.00 a	33.00 a–c	0.00 a	0.00 a	0.00 a	0.00 a
09 VII	52.50 a	3.38 a	16.25 a,b	54.92 c,d	0.25 a	1.88 b	1.50 a	4.68 a,b
06 VIII	49.00 a	3.00 a	10.50 a	31.50 a–c	0.00 a	2.62 b–d	5.00 b	11.90 a–c
03 IX	274.25 a,b	1.62 a	11.50 a,b	18.63 a,b	0.25 a	2.12 b,c	5.75 b,c	16.56 b,c
01 X	469.75 b,c	1.50 a	18.00 b	27.00 a–c	0.50 a	2.75 b–d	8.50 c–e	19.12 c
29 X	617.50 c	2.12 a	16.25 a,b	34.45 a–c	4.25 a	2.50 b–d	7.25 b–e	18.12 b,c
26 XI	527.00 b,c	3.62 a	18.25 b	66.06 d	2.25 a	2.88 b–d	8.50 c–e	18.02 b,c
24 XII	475.75 b,c	2.25 a	9.50 a	21.38 a,b	1.75 a	3.12 b–d	8.00 b–e	15.04 b,c
27 I 1975	287.75 a,b	2.25 a	15.00 a,b	33.75 a–c	2.25 a	3.75	9.75 e	12.19 a–c
18 II	298.50 a,b	2.25 a	12.50 a,b	28.12 a–c	2.25 a	3.62 d	9.25 d,e	12.76 a–c
18 III	103.00 a	3.50 a	11.00 a	38.50 a–d	1.75 a	3.25 c,d	6.50 b–d	11.38 a–c
15 IV	70.25 a	2.75	11.75 a,b	32.31 a–c	0.75 a	2.62 b–d	7.75 b–e	18.44 b,c
13 V	31.50 a	1.50 a	9.75 a	14.62 a	0.75 a	2.62 b–d	9.00 d,e	21.42 c
27 V	75.00 a	3.50 a	13.50 a,b	47.25 b–d	0.50 a	3.75 d	8.00 b–e	10.00 a–c

[a]ODI= (age of OT tunnels)(no./cm^2).

[b]NDI= $[5 -$ (age of NE feeding spots)$]$(no./cm^2).

Table 9.— Monthly averages of _Neochetina eichhorniae_ Warner (NE) and _Orthogalumna terebrantis_ Wallwork (OT) populations and damage data after NE release on an OT-infested mat of waterhyacinth. Values are averages of 4 samples each from Area 9. Values in the same column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Date	Adult OT/Plant	OT Tunnels		ODI[a]	Adult NE/Plant	NE Feeding Spots		NDI[b]
		Age	No./cm^2			Age	No./cm^2	
18 VI 1974	60.00 a	3.00 a	13.00 a-c	39.00 a,b	0.00 a	1.00 a	2.00 a	8.00 a
09 VII	39.75 a	3.50 a	15.75 b,c	55.12 b	0.00 a	2.00 a-c	2.25 a	6.75 a
06 VIII	40.50 a	3.25 a	8.75 a	28.44 a,b	0.00 a	1.62 a,b	4.50 a,b	15.21 a,b
03 IX	281.25 a-c	1.75 a	14.75 a-c	25.81 a	0.75 a	2.12 a-c	6.50 b,c	18.72 a,b
01 X	577.75 d,e	1.50 a	17.00 c	25.50 a	0.50 a	2.50 b-d	9.25 c	23.12 b
29 X	523.00 c-e	2.75 a	11.00 a-c	19.25 a	2.25 a	2.50 b-d	9.00 c	22.50 b
26 XI	772.75 e	1.50 a	13.25 a-c	19.88 a	3.75 a	3.00 c,d	7.50 c	15.00 a,b
24 XII	233.00 a,b	2.38 a	12.00 a-c	28.56 a,b	1.25 a	2.88 b-d	8.75 c	18.55 a,b
27 I 1975	198.25 a,b	2.12 a	10.00 a,b	21.10 a	0.50 a	3.50 d	8.75 c	13.12 a,b
18 II	445.25 a-d	3.00 a	10.25 a-c	30.75 a,b	1.50 a	3.62 d	9.00 c	10.38 a,b
18 III	174.50 a,b	2.75 a	12.75 a-c	35.06 a,b	1.00 a	3.75 d	7.75 c	9.69 a,b
15 IV	86.75 a	3.00 a	10.50 a-c	31.50 a,b	2.25 a	2.75 b-d	8.00 c	18.00 a,b
13 V	156.00 a	3.25 a	10.00 a,b	32.50 a,b	2.00 a	2.75 b-d	9.00 c	20.25 a,b
27 V	31.50 a	1.62	10.25 a-c	16.60 a	0.75 a	3.12 c,d	9.50 c	17.86 a,b

[a] ODI= (age of OT tunnels)(no./cm^2).

[b] NDI= [5 - (age of NE feeding spots)](no./cm^2).

Table 10.— Monthly averages of *Neochetina eichhorniae* Warner (NE) and *Orthogalumna terebrantis* Wallwork (OT) populations and damage data after NE release on an OT-infested mat of waterhyacinth. Values are averages of 4 samples each from Area 10. Values in the same column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Date	Adult OT/Plant	OT Tunnels		ODI[a]	Adult NE/Plant	NE Feeding Spots		NDI[b]
		Age	No./cm^2			Age	No./cm^2	
18 VI 1974.	71.00 a	2.50 a	15.00 d	37.50 a,b	1.00 a,b	1.00 a	4.00 a	16.00 a,b
09 VII	50.75 a	3.25 a	13.00 c,d	42.25 b	0.25 a	1.38 a,b	3.25 a	11.76 a,b
06 VIII	42.25 a	2.12 a	4.75 a	10.07 a	0.75 a,b	1.75 a-c	3.25 a	10.56 a,b
03 IX	362.25 b	2.12 a	11.75 b-d	24.91 a,b	0.00 a	2.50 b-d	3.25 a	8.12 a
01 X	357.75 b	2.38 a	13.00 c,d	30.94 a,b	0.75 a,b	2.38 b-d	5.75 a,b	15.06 a,b
29 X	776.00 c	2.50 a	15.25 d	38.12 a,b	3.50 a,b	2.38 b-d	8.25 b,c	21.62 a,b
26 XI	313.50 a,b	2.38 a	13.75 d	32.72 a,b	3.00 a,b	3.25 d,e	9.25 c	16.19 a,b
24 XII	310.00 a,b	2.12 a	12.00 b-d	25.44 a,b	2.25 a,b	2.75 c-e	7.00 b,c	15.75 a,b
27 I	221.75 a,b	2.12 a	10.75 a-d	22.79 a,b	1.00 a,b	3.50 d,e	8.50 b,c	12.75 a,b
18 II	296.50 a,b	2.12 a	11.50 a-d	24.38 a,b	0.75 a,b	3.25 d,e	9.00 b	15.75 a,b
18 III	66.25 a	2.88 a	11.00 a-d	31.68 a,b	0.25 a	3.88 e	9.25 c	10.36 a,b
15 IV	94.50 a,b	3.00 a	5.75 a,b	17.25 a,b	5.00 b	3.25 d,e	9.75 c	17.06 a,b
13 V	95.00 a,b	1.62 a	6.50 a-c	10.53 a	3.25 a,b	2.75 c-e	9.75 c	21.94 a,b
27 V	135.00 a,b	3.75 a	11.00 a-d	41.25 b	1.00 a,b	2.25 b-d	8.00 b,c	22.00 b

[a]ODI= (age of OT tunnels)(no./cm^2).

[b]NDI= [5- (age of NE feeding spots)](no./cm^2).

Table 11.— Monthly averages of waterhyacinth measurements from plants collected after release of <u>Neochetina eichhorniae</u> Warner. Values are averages of 4 samples each from Area 1. Values in the same column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Date	No. Ps[a]/ Plant	Ps Plants/m^2	Ps/m^2	Ps Dimensions (cm) Width (PsW)	Ps Dimensions (cm) Length (PsL)	Petiole Length (PL) (cm)	Root Length (RL) (cm)	PMF[b]
18 VI 1974	10.00 a	34 b	340.0 a	14.50 a	10.60 a	51.00 c-f	52.00 a	1.50 a
09 VII	9.25 a	34 b	314.5 a	13.16 a	15.50 a	57.08 d-f	42.68 a	2.01 a
06 VIII	10.25 a	34 b	348.5 a	13.96 a	17.22 a	60.10 f	34.04 a	2.68 a
03 IX	9.25 a	34 b	314.5 a	13.45 a	15.38 a	57.58 e,f	49.52 a	1.74 a
01 X	10.50 a	34 b	357.0 a	13.45 a	15.32 a	55.61 d-f	44.08 a	1.88 a
29 X	11.25 a	35 b	393.8 a	13.29 a	13.75 a	46.58 b-f	31.61 a	2.33 a
26 XI	13.75 a	33 b	453.8 a	12.00 a	13.02 a	42.68 b-e	39.68 a	1.71 a
24 XII	10.75 a	34 b	365.5 a	12.65 a	12.42 a	32.08 a,b	34.42 a	1.66 a
27 I 1975	10.75 a	32 b	344.0 a	12.89 a	10.95 a	32.00 a,b	31.50 a	1.77 a
18 II	9.50 a	33 b	313.5 a	12.38 a	10.69 a	25.30 a	27.50 a	1.76 a
18 III	9.50 a	32 b	304.0 a	11.82 a	10.19 a	30.75 a,b	31.00 a	1.70 a
15 IV	10.25 a	33 b	338.2 a	12.15 a	11.04 a	40.80 a-d	28.52 a	2.24 a
13 V	9.75 a	29 b	282.8 a	11.38 a	11.56 a	36.54 a-c	29.02 a	2.05 a
27 V	13.00 a	26 a	338.00 a	10.32 a	10.90 a	35.25 a-c	28.15 a	2.01 a

[a] Ps= pseudolamina(e).

[b] $PMF = \frac{(PsW + PsL + PL)}{RL}$.

Table 12.— Monthly averages of waterhyacinth measurements from plants collected after release of *Neochetina eichhorniae* Warner. Values are averages of 4 samples each from Area 2. Values in the same column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Date	No. Ps[a]/ Plant	Ps Plants/m^2	Ps/m^2	Ps Dimensions (cm) Width (PsW)	Length (PsL)	Petiole Length (PL) (cm)	Root Length (RL) (cm)	PMF[b]
18 VI 1974	10.00 a	34 b	340.00 a	13.65 a	9.90 a	44.20 a–c	21.70 a	3.10 a
09 VII	10.50 a	34 b	357.00 a	12.50 a	13.70 a	56.90 c,d	37.92 a	2.19 a
06 VIII	8.75 a	34 b	297.50 a	14.09 a	17.72 a	68.60 d,e	39.25 a	2.56 a
03 IX	12.25 a	34 b	416.50 a	15.84 a	18.61 a	80.78 e	43.60 a	2.64 a
01 X	9.50 a	34 b	323.00 a	16.12 a	18.10 a	73.00 e	40.71 a	2.63 a
29 X	14.00 a	35 b	490.00 a	15.35 a	17.61 a	70.90 d,e	40.00 a	2.60 a
26 XI	12.75 a	33 b	420.75 a	13.92 a	15.26 a	50.45 b,c	33.05 a	2.41 a
24 XII	10.00 a	34 b	340.00 a	12.94 a	13.01 a	42.80 a–c	24.16 a	2.85 a
27 I 1975	9.75 a	32 b	312.00 a	12.45 a	9.95 a	30.92 a	21.30 a	2.50 a
18 II	8.50 a	33 b	280.50 a	13.32 a	11.60 a	36.58 a,b	29.21 a	2.10 a
18 III	9.25 a	32 b	296.00 a	12.56 a	12.01 a	44.15 a–c	23.60 a	2.91 a
15 IV	10.75 a	33 b	354.75 a	11.16 a	10.89 a	38.20 a,b	25.65 a	2.35 a
13 V	11.25 a	29 b	326.25 a	11.42 a	11.95 a	43.32 a–c	32.30 a	2.06 a
27 V	12.50 a	26 a	325.00 a	13.02 a	15.22 a	45.60 a–c	28.35 a	2.60 a

[a]Ps= pseudolamina(e).

[b]$PMF = \frac{(PsW + PsL + PL)}{RL}$.

Table 13.— Monthly averages of waterhyacinth measurements from plants collected after release of Neochetina eichhorniae Warner. Values are averages of 4 samples each from Area 3. Values in the same column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Date	No. Ps[a]/ Plant	No. Plants/m^2	Ps/m^2	Ps Dimensions (cm) Width (PsW)	Length (PsL)	Petiole Length (PL) (cm)	Root Length (RL) (cm)	PMF[b]
18 VI 1974	9.00 a	34 b	306.00 a	13.65 a	9.90 a	44.20 a	21.70 a	3.10 a
09 VII	10.25 a	34 b	348.50 a	13.51 a	15.92 a	69.90 c	30.69 a	3.24 a
06 VIII	9.00 a	34 b	306.00 a	13.06 a	18.31 a	88.42 d	37.20 a	3.22 a
03 IX	11.00 a	34 b	374.00 a	15.79 a	19.08 a	88.80 d	34.96 a	3.54 a
01 X	10.50 a	34 b	357.00 a	15.88 a	18.25 a	77.82 c,d	40.34 a	2.78 a
29 X	10.50 a	35 b	367.50 a	14.45 a	16.18 a	65.08 b,c	29.94 a	3.20 a
26 XI	14.50 a	33 b	478.50 a	14.05 a	14.75 a	49.78 a,b	32.92 a	2.39 a
24 XII	10.25 a	34 b	348.50 a	13.62 a	13.95 a	46.75 a	33.32 a	2.23 a
27 I 1975	9.50 a	32 b	304.00 a	13.36 a	12.04 a	39.45 a	26.08 a	2.49 a
18 II	10.00 a	33 b	330.00 a	13.05 a	11.49 a	36.85 a	25.38 a	2.42 a
18 III	8.75 a	32 b	280.00 a	10.86 a	10.35 a	41.76 a	25.80 a	2.44 a
15 IV	10.25 a	33 b	338.25 a	12.66 a	12.45 a	43.32 a	26.62 a	2.57 a
13 V	10.00 a	29 b	290.00 a	12.18 a	13.06 a	38.36 a	24.84 a	2.56 a
27 V	11.50 a	26 a	299.00 a	12.05 a	12.75 a	52.95 a,b	26.70 a	2.91 a

[a]Ps= pseudolamina(e).

[b]$PMF = \frac{(PsW + PsL + PL)}{RL}$.

Table 14.— Monthly averages of waterhyacinth measurements from plants collected after release of *Neochetina eichhorniae* Warner. Values are averages of 4 samples each from Area 4. Values in the same column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Date	No. Ps[a]/ Plant	No. Plants/m^2	Ps/m^2	Ps Dimensions (cm) Width (PsW)	Length (PsL)	Petiole Length (PL) (cm)	Root Length (RL) (cm)	PMF[b]
18 VI 1974	7.00 a	34 b	238.00 a	11.70 a	13.85 a	47.20 a	37.30 a	2.00 a
09 VII	8.00 a	34 b	272.00 a	11.74 a	15.29 a	68.42 b	20.58 a	3.12 a
06 VIII	7.25 a	34 b	246.50 a	14.45 a	19.29 a	85.00 c	37.82 a	3.14 a
03 IX	8.00 a	34 b	272.00 a	13.94 a	17.00 a	84.40 c	26.26 a	4.39 a
01 X	9.00 a	34 b	306.00 a	14.89 a	18.69 a	87.91 c	33.64 a	3.61 a
29 X	10.50 a	35 b	367.50 a	14.84 a	16.95 a	65.40 b	31.80 a	3.06 a
26 XI	12.00 a	33 b	396.00 a	14.62 a	15.76 a	45.25 a	27.98 a	2.70 a
24 XII	9.72 a	34 b	331.50 a	12.35 a	12.78 a	42.48 a	26.60 a	2.54 a
27 I 1975	9.00 a	32 b	288.00 a	13.00 a	12.29 a	38.62 a	31.18 a	2.05 a
18 II	10.25 a	33 b	338.25 a	12.68 a	10.15 a	39.28 a	26.19 a	2.37 a
18 III	8.75 a	32 b	280.00 a	12.91 a	11.72 a	46.52 a	20.34 a	3.50 a
15 IV	10.25 a	33 b	338.25 a	13.28 a	12.42 a	46.50 a	23.11 a	3.12 a
13 V	8.50	29 b	246.50 a	11.99 a	12.85 a	49.60 a	21.68 a	3.43 a
27 V	11.50 a	26 a	299.00	13.35 a	13.35 a	14.02 a	53.95 a,b	3.25 a

[a]Ps= pseudolamina(e).

[b]PMF= $\frac{(PsW + PsL + PL)}{RL}$.

Table 15.— Monthly averages of waterhyacinth measurements from plants collected after release of *Neochetina eichhorniae* Warner. Values are averages of 4 samples each from Area 5. Values in the same column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Date	No. Ps[a]/ Plant	No. Plants/m^2	Ps/m^2	Ps Dimensions (cm) Width (PsW)	Length (PsL)	Petiole Length (PL) (cm)	Root Length (RL) (cm)	PMF[b]
18 VI 1974	9.00 a	34 a	306.00 a	14.10 a	10.30 a	57.00 d,e	47.30 a	1.70 a
09 VII	8.85 a	34 a	297.50 a	11.05 a	12.19 a	52.92 c,d	28.02 a	2.72 a
06 VIII	9.50 a	34 a	323.00 a	13.92 a	17.50 a	71.78 e,f	36.12 a	2.86 a
03 IX	10.00 a	34 a	340.00 a	16.15 a	19.12 a	75.52 f	30.25 a	3.66 a
01 X	11.00 a	34 a	374.00 a	15.05 a	18.14 a	85.38 f	33.60 a	3.53 a
29 X	9.25 a	35 a	323.75 a	14.46 a	16.78 a	72.45 e,f	26.92 a	3.85 a
26 XI	15.25 a	33 a	503.25 a	14.24 a	14.50 a	43.70 a-d	25.65 a	2.82 a
24 XII	12.00 a	34 a	408.00 a	13.64 a	13.25 a	34.80 a,b	27.28 a	2.26 a
27 I 1975	11.00 a	32 a	352.00 a	11.85 a	9.25 a	27.30 a	30.75 a	1.57 a
18 II	9.50 a	33 a	313.50 a	13.25 a	10.16 a	32.68 a	25.12 a	2.23 a
18 III	10.50 a	32 a	336.00 a	13.54 a	11.21 a	36.70 a-c	26.45 a	2.32 a
15 IV	9.00 a	33 a	297.00 a	12.34 a	11.60 a	40.42 a-c	24.45 a	2.63 a
13 V	8.00 a	29 a	232.00 a	11.16a	10.65 a	42.88 a-d	27.98 a	2.31 a
27 V	9.00 a	31 a	279.00 a	11.88 a	12.92 a	49.85 b-d	18.90 a	3.95 a

[a]Ps= pseudolamina(e).

[b]PMF= $\frac{(PsW + PsL + PL)}{RL}$.

Table 16.— Monthly averages of waterhyacinth measurements from plants collected after release of *Neochetina eichhorniae* Warner. Values are averages of 4 samples each from Area 6. Values in the same column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Date	No. Ps[a]/ Plant	No. Plants/m^2	Ps/m^2	Ps Dimensions (cm) Width (PsW)	Length (PsL)	Petiole Length (PL) (cm)	Root Length (RL) (cm)	PMF[b]
18 VI 1974.	7.00 a	34 a	238.00 a	10.30 a	9.70 a	49.00 c,d	31.70 a	2.20 a
09 VII	7.25 a	34 a	246.50 a	9.20 a	10.98 a	43.02 a-c	25.80 a	2.45 a
06 VIII	9.00 a	34 a	306.00 a	11.65 a	17.25 a	63.40 d-f	32.30 a	2.86 a
03 IX	10.50 a	34 a	357.00 a	13.26 a	15.75 a	68.25 e,f	32.66 a	2.98 a
01 X	10.50 a	34 a	357.00 a	13.55 a	14.91 a	53.60 c-e	32.68 a	2.51 a
29 X	12.75 a	35 a	446.25 a	15.58 a	17.26 a	71.48 f	35.42 a	2.94 a
26 XI	13.25 a	33 a	437.25 a	15.74 a	16.34 a	47.35 b,c	25.85 a	3.07 a
24 XII	12.25 a	34 a	416.50 a	13.16 a	12.08 a	32.30 a,b	21.90 a	2.63 a
27 I 1975	11.00 a	32 a	352.00 a	11.69 a	9.81 a	27.22 a	24.04 a	2.03 a
18 II	10.00 a	33 a	330.00 a	12.20 a	10.92 a	39.85 a-c	20.55 a	2.06 a
18 III	10.00 a	32 a	320.00 a	12.92 a	10.42 a	37.22 a-c	27.22 a	2.22 a
15 IV	9.25 a	33 a	305.25 a	11.30 a	10.51 a	40.68 a-c	21.68 a	2.88 a
13 V	8.50 a	29 a	246.50 a	11.36 a	12.85 a	46.55 b,c	20.32 a	3.48 a
27 V	9.00 a	34 a	306.00 a	11.45 a	12.10 a	46.15 b,c	17.72 a	3.20 a

[a]Ps= pseudolamina(e).

[b]$PMF = \frac{(PsW + PsL + PL)}{RL}$.

Table 17.— Monthly averages of waterhyacinth measurements from plants collected after release of <u>Neochetina eichhorniae</u> Warner. Values are averages of 4 samples each from Area 7. Values in the same column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Date	No. Ps[a]/ Plant	No. Plants/m^2	Ps/m^2	Ps Dimensions (cm) Width (PsW)	Ps Dimensions (cm) Length (PsL)	Petiole Length (PL) (cm)	Root Length (RL) (cm)	PMF[b]
18 VI 1974	7.00 a	34 a	238.00 a	16.00 a	11.90 a	56.50 b–d	26.90 a	3.10 a
09 VII	8.00 a	34 a	272.00 a	12.08 a	14.82 a	65.30 d,e	26.50 a	3.48 a
06 VIII	8.00 a	34 a	272.00 a	13.38 a	18.01 a	86.82 f	26.30 a	4.50 a
03 IX	9.50 a	34 a	323.00 a	15.50 a	19.32 a	83.55 f	40.58 a	2.92 a
01 X	9.25 a	34 a	314.50 a	14.73 a	17.80 a	73.49 e,f	38.04 a	2.79 a
29 X	12.25 a	35 a	428.75 a	14.79 a	15.92 a	57.40 c,d	33.25 a	2.65 a
26 XI	11.50 a	33 a	379.50 a	12.52 a	14.98 a	52.32 b–d	26.09 a	3.06 a
24 XII	11.75 a	34 a	399.50 a	14.18 a	13.90 a	40.32 a,b	26.58 a	2.56 a
27 I 1975	9.50 a	32 a	304.00 a	12.62 a	21.39 a	29.22 a	27.80 a	2.27 a
18 II	10.00 a	33 a	330.00 a	12.59 a	10.40 a	30.42 a	21.28 a	2.51 a
18 III	9.75 a	32 a	312.00 a	13.71 a	12.10 a	45.08 a–c	22.75 a	3.12 a
15 IV	9.25 a	33 a	305.25 a	12.49 a	12.69 a	46.75 b,c	21.90 a	3.28 a
13 V	9.00 a	29 a	261.00 a	13.04 a	13.85 a	53.55 b–d	23.58 a	3.41 a
27 V	10.00 a	27 a	270.00 a	11.68 a	13.08 a	53.55 b–d	24.40 a	3.21 a

[a] Ps= pseudolamina(e).

[b] $PMF = \frac{(PsW + PsL + PL)}{RL}$.

Table 18.— Monthly averages of waterhyacinth measurements from plants collected after release of _Neochetina eichhorniae_ Warner. Values are averages of 4 samples each from Area 8. Values in the same column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Date	No. Ps[a]/ Plant	No. Plants/m^2	Ps/m^2	Ps Dimensions (cm) Width (PsW)	Ps Dimensions (cm) Length (PsL)	Petiole Length (PL) (cm)	Root Length (RL) (cm)	PMF[b]
18 VI 1974	7.00 a	34 a	238.00 a	17.60 a	15.35 a	87.00 d	31.00 a	3.90 a
09 VII	7.00 a	34 a	238.00 a	13.62 a	17.31 a	79.80 c,d	37.62 a	2.94 a
06 VIII	8.75 a	34 a	297.50 a	14.58 a	19.69 a	93.20 d	42.08 a	3.03 a
03 IX	10.75 a	34 a	365.50 a	14.35 a	18.55 a	84.05 c,d	32.90 a	3.56 a
01 X	8.75 a	34 a	297.50 a	15.32 a	17.62 a	70.52 c	32.22 a	3.21 a
29 X	10.25 a	35 a	358.75 a	14.29 a	15.66 a	51.72 b	35.98 a	2,27 a
26 XI	12.75 a	33 a	420.75 a	13.42 a	14.58 a	50.30 b	34.28 a	2.28 a
24 XII	11.00 a	34 a	374.00 a	13.10 a	13.25 a	32.72 a	23.85 a	2.48 a
27 I 1975	11.00 a	32 a	352.00 a	13.15 a	11.61 a	40.68 a,b	28.02 a	2.34 a
18 II	10.00 a	33 a	330.00 a	13.45 a	11.81 a	45.52 a,b	24.52 a	2.89 a
18 III	9.00 a	32 a	288.00 a	11.85 a	11.02 a	47.20 a,b	18.45 a	3.80 a
15 IV	8.25 a	33 a	272.25 a	12.45 a	12.62 a	45.08 a,b	20.06 a	3.50 a
13 V	7.25 a	29 a	210.25 a	11.10 a	11.88 a	49.20 b	21.48 a	3.36 a
27 V	9.00 a	28 a	252.00 a	12.32 a	14.00 a	54.00 b	20.80 a	3.86 a

[a]Ps= pseudolamina(e).

[b]PMF= $\frac{(PsW + PsL + PL)}{RL}$.

Table 19.— Monthly averages of waterhyacinth measurements from plants collected after release of *Neochetina eichhorniae* Warner. Values are averages of 4 samples each from Area 9. Values in the same column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Date	No. Ps[a]/ Plant	No. Plants/m^2	Ps/m^2	Ps Dimensions (cm) Width (PsW)	Length (PsL)	Petiole Length (PL) (cm)	Root Length (RL) (cm)	PMF[b]
18 VI 1974	7.00 a	34 a	238.00 a	15.45 a	12.00 a	76.00 b,c	48.40 a	2.10 a
09 VII	9.00 a	34 a	306.00 a	15.45 a	17.51 a	84.50 c	43.70 a	2.69 a
06 VIII	7.75 a	34 a	263.50 a	13.34 a	17.81 a	76.08 b,c	48.42 a	2.21 a
03 IX	11.25 a	34 a	382.50 a	15.86 a	19.46 a	90.85 c	43.75 a	2.88 a
01 X	8.25 a	34 a	280.50 a	14.19 a	16.99 a	64.24 b	31.38 a	3.04 a
29 X	10.50 a	35 a	367.50 a	15.08 a	17.24 a	65.59 b	37.74 a	2.59 a
26 XI	12.50 a	33 a	412.50 a	14.90 a	15.52 a	48.92 a	34.30 a	2.31 a
24 XII	10.50 a	34 a	357.00 a	13.49 a	14.35 a	43.60 a	21.15 a	3.38 a
27 I 1975	9.50 a	32 a	304.00 a	13.52 a	11.79 a	39.75 a	21.08 a	3.09 a
18 II	10.25 a	33 a	338.25 a	13.66 a	12.30 a	39.75 a	23.31 a	2.82 a
18 III	8.75 a	32 a	280.00 a	12.24 a	11.40 a	45.15 a	20.92 a	3.29 a
15 IV	9.75 a	33 a	321.75 a	11.65 a	11.32 a	42.48 a	24.58 a	2.66 a
13 V	9.00 a	29 a	261.00 a	11.20 a	11.90 a	39.58 a	22.65 a	2.77 a
27 V	13.00 a	27 a	351.00 a	11.60 a	13.92 a	39.10 a	29.50 a	2.19 a

[a]Ps= pseudolamina(e).

[b]PMF= $\frac{(PsW + PsL + PL)}{RL}$.

Table 20.— Monthly averages of waterhyacinth measurements from plants collected after release of *Neochetina eichhorniae* Warner. Values are averages of 4 samples each from Area 10. Values in the same column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Date	No. Ps[a]/ Plant	No. Plants/m^2	Ps/m^2	Ps Dimensions (cm) Width (PsW)	Ps Dimensions (cm) Length (PsL)	Petiole Length (PL) (cm)	Root Length (RL) (cm)	PMF[b]
18 VI 1974	7.00 a	34 b	238.00 a	14.17 a	11.77aa	61.06 c	35.53 a	2.50 a
09 VII	9.00 a	34 b	306.00 a	13.37 a	15.54 a	64.64 c	38.93 a	2.40 a
06 VIII	8.85 a	34 b	297.50 a	12.35 a	15.78 a	64.50 c	39.20 a	2.36 a
03 IX	11.75 a	34 b	399.50 a	13.68 a	17.40 a	70.59 c	43.34 a	2.34 a
01 X	8.75 a	34 b	297.50 a	14.78 a	16.64 a	69.44 c	37.24 a	2.70 a
29 X	12.50 a	35 b	437.50 a	13.61 a	15.86 a	58.18 b,c	32.26 a	2.72 a
26 XI	13.00 a	33 b	429.00 a	13.20 a	13.14 a	40.20 a	35.08 a	1.90 a
24 XII	9.50 a	34 b	323.00 a	13.09 a	12.56 a	39.20 a	23.80 a	2.72 a
27 I 1975	9.50 a	32 b	304.00 a	12.00 a	11.29 a	39.65 a	31.79 a	1.98 a
18 II	10.50 a	33 b	346.50 a	12.45 a	11.39 a	43.65 a,b	30.58 a	2.21 a
18 III	9.50 a	32 b	304.00 a	11.90 a	11.04 a	44.55 a,b	22.69 a	2.97 a
15 IV	9.75 a	33 b	321.75 a	10.66 a	10.85 a	35.84 a	26.81 a	2.14 a
13 V	9.25 a	29 b	268.25 a	10.32 a	10.91 a	31.58 a	29.22 a	1.81 a
27 V	9.00 a	24 a	216.00 a	9.40 a	11.25 a	41.70 a	26.58 a	2.34 a

[a]Ps= pseudolamina(e).

[b]PMF= $\frac{(PsW + PsL + PL)}{RL}$.

Table 21.— Least-squares analyses of variance for Neochetina eichhorniae Warner (NE), Orthogalumna terebrantis Wallwork (OT) and waterhyacinth (WH) parameters for NE release experiment.

Source		df	Sum of Squares	Mean Square	F
NE-	Date	50	10152.2273	203.0446	37.99**
	Area	9	239.6309	26.6256	4.98**
OT-	Date	50	33288866.9000	665777.3390	9.63**
No. WH Ps[a]-					
	Date	50	1036.5036	20.7301	4.84**
	Area	9	72.4977	8.0553	1.88*
OT Damage-	Date	49	47947.5920	978.5223	2.67**
	Area	9	4083.1520	453.6836	1.24*
NE Damage-	Date	49	7983.4020	162.9266	3.52**
Ps Width-	Date	49	758.1626	15.4727	6.50**
	Area	9	81.9143	9.1016	3.83**
Ps Length-	Date	49	3657.9383	74.6518	26.93**
	Area	9	202.8048	22.5339	8.13**
Petiole Length-	Date	49	119502.7390	2438.8314	25.57**
	Area	9	11535.9160	1281.7684	13.44**
Root Length-	Date	49	16687.5815	340.5629	4.75**
	Area	9	3281.7111	364.6346	5.08**
Male NE-	Date	49	242.4880	4.9487	2.47**
Female NE-	Date	49	192.7780	3.9342	2.14*
	Area	9	33.5780	3.7309	2.03*
PMF[b]-	Date	49	106.8468	2.1806	1.96*
	Area	9	61.1792	6.7977	6.10**

[a]Ps= pseudolamina(e).

[b]PMF= $\frac{\text{(Ps Width + Ps Length + Petiole Length)}}{\text{Root Length}}$.

*P= 0.05.

**P= 0.01.

Table 22.— Least-squares analyses of variance for Neochetina eichhorniae Warner (NE), Orthogalumna terebrantis Wallwork (OT) and waterhyacinth (WH) parameters for coffin-holder experiment.

Source	df	Septe-nary	Sum of Squares	Mean Square	F
NE- Treatment (T)	6	1	894.48	149.08	8.27**
Block (B)	2	4	0.07	0.04	3.00*
B	2	6	0.07	0.04	3.00*
B x T	6	6	0.67	0.11	9.00**
B	2	7	0.30	0.15	3.00*
OT- B	2	3	7302.13	3651.06	3.82*
T	6	5	4125.63	687.60	3.92*
B	2	7	312.67	156.33	3.17*
NE Damage- B	2	2	40.07	20.04	5.56**
T	6	2	468.07	78.12	21.64**
B	2	7	604.96	302.48	9.69**
OT Damage- B	2	2	6889.56	3444.78	14.88**
B	2	3	593.27	296.64	4.79*
T	6	3	3095.76	515.96	8.34**
B x T	6	3	2262.67	377.11	6.09**
Ps[a] Width- B	2	2	3.50	1.75	3.72*
T	6	2	8.89	1.48	3.15*
T	6	3	8.81	1.47	7.57**
B	2	4	6.57	3.28	3.61*
B	2	5	5.82	2.91	4.90**
B	2	6	7.86	3.93	6.09**
B	2	7	19.78	9.89	6.39**
Ps Length- B	2	2	1.65	0.83	4.24**
B	2	5	2.21	1.10	4.32*
B	2	6	3.18	1.59	3.75*
B	2	7	21.69	10.84	5.02**
Petiole Length- B	2	2	4.03	2.01	3.52*
T	6	2	12.35	2.06	3.60*
T	6	3	5.79	0.96	3.27*
B x T	6	3	5.88	0.98	3.32*
B	2	6	17.64	8.82	5.78**
B	2	7	93.85	46.92	4.68*
Root Length- B	2	1	715.47	357.74	5.89**

Table 22.— Continued.

Source		df	Septe-nary	Sum of Squares	Mean Square	F
No. WH Ps/Plant-	B	2	2	6.22	3.11	6.22**
	T	6	2	10.44	1.74	3.48*
	B	2	3	36.41	18.20	3.19*
	B	2	4	42.00	21.00	9.61**
	BxT	6	4	46.00	7.67	3.51*
	B	2	5	12.96	6.48	7.34**
	T	6	5	17.41	2.90	3.29*
	B	2	6	22.30	11.15	4.95**
	T	6	6	49.85	8.31	3.69*
	B	2	7	44.74	22.37	7.16**
WH Density/m^2-	B	2	2	304.22	152.11	4.51*
	B	2	3	1998.35	999.17	5.20**
	B	2	4	10854.89	5427.44	4.35**
	B	2	5	19153.56	9576.78	4.33*
	B	2	6	19590.22	9795.11	4.41*
	B	2	7	16576.07	8288.04	4.49*
WH Wet Weight-	B	2	2	8597.42	4298.71	7.41**
PMF[b]-	B	2	4	0.15	0.08	12.58**
	T	6	4	0.46	0.08	12.44**
	B	2	5	0.28	0.14	3.36*
	B	2	6	0.85	0.42	4.56*
	BxT	6	6	3.91	0.65	7.01**

[a]Ps= pseudolamina(e).

[b]PMF= $\frac{\text{(Ps Width + Ps Length + Petiole Length)}}{\text{Root Length}}$.

*P= 0.05.

**P= 0.01.

Table 23.— Septenarial averages of <u>Neochetina eichhorniae</u> Warner (NE), <u>Orthogalumna terebrantis</u> Wallwork (OT) and waterhyacinth (WH) parameters for coffin-holder experiment in which only OT was added to WH. Values are averages of 21 samples each. Values in the same row followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Source	Septenary No. 1	2	3	4	5	6	7
No. NE/Plant	0.33 b	0.00 a	0.00 a	0.00 a	0.00 a	0.83 c	0.00 a
NE Feeding Spots							
Age	0.92 a	2.96 a	3.46 a	3.29 a	2.33 a	2.17 a	1.40 a
No./cm^2	0.58 a	3.17 a	6.75 a	6.83 a	5.00 a	3.83 a	2.80 a
NDI[a]	2.37 a	6.47 a,b	10.40 b,c	11.68 b,c	13.35 c	10.84 b,c	10.08 b,c
No. OT/Plant	31.08 b	17.42 a,b	4.50 a	3.25 a	0.00 a	1.42 a	0.27 a
OT Tunnels							
Age	1.59 a	3.75 a	2.42 a	0.29 a	0.00 a	0.08 a	0.27 a
No./cm^2	8.33 b,c	9.50 c	2.25 a,b	0.33 a	0.00 a	0.58 a	0.27 a
ODI[b]	13.24 a	35.62 b	5.44 a	0.10 a	0.00 a	0.05 a	0.07 a
No. Ps[c]							
Per Plant	7.08 a	[illegible].42 a	6.92 a	5.58 a	5.17 a	4.42 a	4.00 a
Per Coffin-Holder	170.58 a	258.17 a	207.58 a	146.75 a	77.50 a	29.00 a	11.73 a
No. WH/Coffin-Holder	24.17 c,d	30.58 d	26.50 c,d	21.33 c,d	14.58 b,c	6.67 a,b	2.87 a
Ps Width (cm) (PsW)	7.11 a	4.28 a	3.46 a	2.59 a	2.39 a	1.92 a	1.81 a
Ps Length (cm) (PsL)	6.18 a	3.94 a	3.64 a	2.63 a	2.11 a	1.62 a	1.62 a
Petiole Length (cm) (PL)	9.01 a	5.17 a	4.62 a	3.38 a	2.62 a	2.20 a	2.31 a
Root Length (cm) (RL)	27.13 b	28.67 b	22.56 a,b	25.25 a,b	31.19 b	20.95 a,b	13.63 a

Table 23.— Continued.

Source	Septenary No.						
	1	2	3	4	5	6	7
WH Weight (g)							
Wet	144.78 a	117.66 a	93.25 a	118.21 a	118.88 a	76.47 a	102.85 a
Dry	-	-	-	-	-	-	3.34
PMF[d]	0.82 a	0.47 a	0.52	0.34 a	0.23 a	0.27 a	0.42 a

[a]NDI= [5 - (age of NE feeding spots)](no./cm^2).

[b]ODI= (age of OT tunnels)(no./cm^2).

[c]Ps= pseudolamina(e).

[d]PMF= $\frac{(PsW + PsL + PL)}{RL}$.

Table 24.— Septenarial averages of <u>Neochetina eichhorniae</u> Warner (NE), <u>Orthogalumna terebrantis</u> Wallwork (OT) and Waterhyacinth (WH) parameters for coffin-holder experiment in which only NE was added to WH. Values are averages of 21 samples each. Values in the same row followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Source	Septenary No. 1	2	3	4	5	6	7
No. NE/Plant	0.50 b	0.00 a	0.25 a,b	0.00 a	0.00 a	0.25 a,b	0.00 a
NE Feeding Spots							
Age No./cm^2	2.00 a	3.29 a	3.25 a	3.17 a	3.34 a	2.46 a	2.00 a
	6.32 a	7.33 a	7.00 a	5.58 a	5.25 a	5.92 a	4.13 a
NDI[a]	18.96 c	12.53 a,b	12.25 a,b	10.21 a,b	8.72 a	15.04 b,c	12.39 a,b
No. OT/Plant	19.08 a	3.00 a	0.75 a	0.83 a	0.00 a	0.00 a	0.40 a
OT Tunnels							
Age No./cm^2	2.00 a	1.21 a	0.33 a	0.29 a	0.00 a	0.00 a	0.07 a
	4.58 a	2.83 a	0.17 a	0.50 a	0.00 a	0.00 a	0.17 a
ODI[b]	9.16 a	3.42 a	0.06 a	0.14 a	0.00 a	0.00 a	0.01 a
No. Ps[c]							
Per Plant	6.88 a	8.25 a	8.33 a	6.83 a	6.00 a	5.00 a	4.67 a
Per Coffin-Holder	151.88 a	200.92 a	186.92 a	108.83 a	79.00 a	58.58 a	35.27 a
No. WH/Coffin-Holder	21.25 b,c	24.25 c	21.83 b,c	15.75 a–c	13.25 a,b	11.17 a	7.20 a
Ps Width (cm) (PsW)	6.60 a	4.29 a	3.70 a	2.91 a	2.55 a	2.14 a	1.74 a
Ps Length (cm) (PsL)	5.97 a	3.65 a	3.40 a	2.51 a	2.36 a	1.84 a	1.63 a
Petiole Length (cm) (PL)	11.62 a	4.70 a	4.70 a	3.37 a	3.30 a	2.61 a	2.34 a
Root Length (cm) (RL)	30.76 b	24.86 a,b	23.29 a,b	20.92 a,b	21.79 a,b	20.33 a,b	14.45 a

Table 24.— Continued.

Source	Septenary No.						
	1	2	3	4	5	6	7
WH Weight (g)							
Wet	161.67 a	104.57 a	111.61 a	94.67 a	104.00 a	87.10 a	68.18 a
Dry	-	-	-	-	-	-	3.
PMF[d]	0.79 a	0.51 a	0.51 a	0.42 a	0.38 a	0.32 a	0.40 a

[a] NDI= [5 - (age of NE feeding spots)](no./cm^2).

[b] ODI= (age of OT tunnels)(no./cm^2).

[c] Ps= pseudolamina(e).

[d] PMF= $\frac{(PsW + PsL + PL)}{RL}$.

Table 25.— Septenarial averages of _Neochetina eichhorniae_ Warner (NE), _Orthogalumna terebrantis_ Wallwork (OT) and waterhyacinth (WH) parameters for coffin-holder experiment in which NE and OT were added simultaneously to WH. Values are averages of 21 samples each. Values in the same row followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Source	Septenary No. 1	2	3	4	5	6	7
No. NE/Plant	0.50 b	0.83 c	0.00 a	0.83 c	0.00 a	0.00 a	0.00 a
NE Feeding Spots							
Age	2.59 a	3.30 a	3.25 a	3.13 a	2.21 a	3.38 a	2.97 a
No./cm^2	6.33 a	6.92 a	7.42 a	5.17 a	2.33 a	6.83 a	6.13 a
NDI[a]	15.26 b	11.76 a,b	12.98 b	9.67 a,b	6.50 a	11.06 a,b	12.44 a,b
No. OT/Plant	82.33 b	9.75 a	6.50 a	0.50 a	0.50 a	2.33 a	2.47 a
OT Tunnels							
Age	2.50 a	2.25 a	1.17 a	0.29 a	0.00 a	0.83 a	0.70 a
No./cm^2	13.17 b	5.50 a	0.50 a	0.50 a	0.00 a	0.33 a	1.07 a
ODI[b]	32.92 b	12.38 a	0.58 a	0.14 a	0.00 a	0.27 a	0.75 a
No. Ps[c]							
Per Plant	6.17 a	8.42 a	8.42 a	5.58 a	5.33 a	5.50 a	6.33 a
Per Coffin-Holder	147.00 a	235.50 a	207.33 a	104.83 a	82.67 a	64.58 a	52.27 a
No. WH/Coffin-Holder	23.58 c,d	26.42 d	23.83 c,d	20.13 c,d	15.33 a-c	11.83 a,b	7.60 a
Ps Width (cm)(PsW)	7.35 a	5.08 a	4.49 a	3.95 a	2.73 a	2.25 a	2.41 a
Ps Length (cm) (sL)	6.69 a	4.31 a	4.03 a	3.47 a	2.41 a	2.02 a	2.01 a
Petiole Length (cm) (PL)	8.99 a	6.56 a	5.67 a	4.48 a	3.14 a	2.79 a	3.05 a
Root Length (cm) (RL)	27.48 a	21.02 a	23.03 a	20.76 a	23.96 a	22.24 a	15.73 a

Table 25.— Continued.

Source	Septenary No. 1	2	3	4	5	6	7
WH Weight (g)							
Wet	191.85 a	131.89 a	137.87 a	102.50 a	120.64 a	102.32 a	101.21 a
Dry	-	-	-	-	-	-	3.00
PMF[d]	0.84 a	0.76 a	0.62 a	0.57 a	0.34 a	0.32 a	0.48 a

[a]NDI= [5 - (age of NE feeding spots)](no./cm^2).

[b]ODI= (age of OT tunnels)(no./cm^2).

[c]Ps= pseudolamina(e).

[d]PMF= $\left(\frac{\text{PsW + PsL + [illegible]}}{\text{RL}}\right)$.

Table 26.— Septenarial averages of *Neochetina eichhorniae* Warner (NE), *Orthogalumna terebrantis* Wallwork (OT) and waterhyacinth (WH) parameters for coffin-holder experiment in which NE was added to WH 3 months before OT was added. Values are averages of 21 samples each. Values in the same row followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Source	Septenary No. 1	2	3	4	5	6	7
No. NE/Plant	0.58 b	0.83 b	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a
NE Feeding Spots							
Age	2.42 a	3.96 a	3.21 a	3.55 a	3.50 a	3.25 a	2.79 a
NO./cm^2	7.75 a	9.83 a	7.50 a	7.33 a	5.33 a	6.67 a	6.53 a
NDI[a]	14.84 b	10.22 a,b	13.42 a,b	10.63 a,b	8.00 a	11.67 a,b	14.43 b
No. OT/Plant	3.25 a	29.00 b	2.67 a	0.67 a	0.00 a	4.00 a	0.40 a
OT Tunnels							
Age	2.04 a	2.58 a	1.33 a	0.29 a	0.00 a	0.83 a	0.00 a
No./cm^2	5.25 a	3.83 a	1.50 a	0.17 a	0.00 a	0.33 a	0.00 a
ODI[b]	10.71 a	9.88 a	2.00 a	0.05 a	0.00 a	0.27 a	0.00 a
No. Ps[c]							
Per Plant	5.50 a	7.92 a	7.33 a	5.92 a	6.50 a	5.75 a	6.00 a
Per Coffin-Holder	117.33 a	213.33 a	161.08 a	94.92 a	73.42 a	55.25 a	46.78 a
No. WH/Coffin-Holder	21.67 b,c	26.83 c	22.50 b,c	15.08 a,b	11.00 a	9.17 a	8.10 a
Ps Width (cm) (PsW)	6.34 a	3.87 a	3.14 a	2.79 a	2.59 a	2.02 a	2.18 a
Ps Length (cm) (PsL)	6.23 a	3.67 a	3.21 a	2.73 a	2.31 a	1.85 a	1.98 a
Petiole Length (cm) (PL)	7.31 a	4.95 a	5.10 a	3.68 a	3.18 a	2.62 a	2.96 a
Root Length (cm) (RL)	31.78 b	19.02 a	15.82 a	17.96 a	18.74 a	17.68 a	18.93 a

Table 26.— Continued.

Source	Septenary No. 1	2	3	4	5	6	7
WH Weight (g)							
Wet	139.12 a	97.43 a	97.28 a	96.93 a	103.29 a	95.19 a	90.28 a
Dry	-	-	-	-	-	-	3.87
PMF[d]	0.62 a	0.66 a	0.72 a	0.51 a	0.43 a	0.37 a	0.38 a

[a]NDI= [5 - (age of NE feeding spots)](no./cm^2).

[b]ODI= (age of OT tunnels)(no./cm^2).

[c]Ps= pseudolamina(e).

[d]PMF= $\frac{(PsW + PsL + PL)}{RL}$.

Table 27.— Septenarial averages of _Neochetina eichhorniae_ Warner (NE), _Orthogalumna terebrantis_ Wallwork (OT) and waterhyacinth (WH) parameters for coffin-holder experiment in which OT was added to WH 3 months before NE was added. Values are averages of 21 samples each. Values in the same row followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Source	Septenary No. 1	2	3	4	5	6	7
No. NE/Plant	0.08 a	0.08 a	0.00 a	0.00 a	0.08 a	0.67 b	0.40 b
NE Feeding Spots							
Age	0.54 a	2.38 a,b	3.13 a,b	3.79 b	3.42 b	2.17 a,b	1.87 a,b
No./cm^2	0.75 a	5.00 a,b	8.25 b	7.25 b	5.92 a,b	5.67 a,b	4.53 a,b
NDI[a]	3.34 a	13.10 b,c	15.43 c	27.48 d	9.35 b	16.05 c	14.18 b,c
No. OT/Plant	55.50 c	31.42 b	30.08 b	6.17 a	1.08 a	20.67 a,b	11.67 a,b
OT Tunnels							
Age	2.25 a	2.71 a	1.83 a	0.25 a	0.17 a	0.67 a	0.43 a
No./cm^2	10.33 b	10.92 b	2.17 a	0.42 a	0.67 a	0.75 a	1.00 a
ODI[b]	23.24 b	29.59 b	3.97 a	0.10 a	0.11 a	0.50 a	0.43 a
No. Ps[c]							
Per Plant	7.00 a	8.58 a	8.25 a	6.83 a	7.67 a	6.25 a	6.60 a
Per Coffin-Holder	201.67 a	343.50 a	385.83 a	385.92 a	753.58 b	638.92 b	714.87 b
No. WH/Coffin-Holder	28.58 a	38.75 b	43.50 b,c	50.33 c	71.17 d	71.67 d	69.00 d
Ps Width (cm) (PsW)	7.09 a	4.46 a	3.79 a	3.62 a	3.20 a	3.04 a	2.81 a
Ps Length (cm) (PsL)	6.97 a	4.25 a	3.62 a	3.08 a	2.76 a	2.42 a	2.41 a
Petiole Length (cm) (PL)	10.03 a	5.16 a	5.96 a	4.30 a	3.68 a	4.24 a	5.04 a
Root Length (cm) (RL)	29.00 a–c	32.48 a–c	35.36 b,c	26.88 a,b	39.97 c	30.01 a–c	22.04 a

Table 27.— Continued.

Source	Septenary No.						
	1	2	3	4	5	6	7
WH Weight (g)							
Wet	184.59 a	110.78 a	150.37 a	121.18 a	145.92 a	94.30 a	85.64 a
Dry	-	—	-	-	-	-	3.51
PMF[d]	0.83 a	0.43 a	0.39 a	0.41 a	0.24 a	0.32 a	0.47 a

[a]NDI= [5 - (age of NE feeding spots)](no./cm^2).

[b]ODI= (age of OT tunnels)(no./cm^2).

[c]Ps= pseudolamina(e);

[d]PMF= $\frac{(PsW + PsL + PL)}{RL}$.

Table 28.— Septenarial averages of *Neochetina eichhorniae* Warner (NE), *Orthogalumna terebrantis* Wallwork (OT) and waterhyacinth (WH) parameters for covered control coffin-holders. Values are averages of 21 samples each. Values in the same row followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Source	Septenary No. 1	2	3	4	5	6	7
No. NE/Plant	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.13 a
NE Feeding Spots							
Age	0.33 a	0.38 a	0.00 a	1.42 a	1.33 a	1.29 a	2.30 a
No./cm^2	0.42 a	0.42 a	0.00 a	2.00 a	1.92 a	2.67 a	5.20 a
NDI[a]	1.96 a,b	1.94 a,b	0.00 a	7.16 b,c	7.05 b,c	9.91 c,d	14.04 d
No. OT/Plant	8.96 a	46.33 b	41.42 b	89.67 c	28.17 a,b	39.42 b	33.60 b
OT Tunnels							
Age	1.96 a	2.33 a	2.54 a	1.83 a	2.04 a	1.50 a	1.77 a
No./cm^2	7.25 a,b	13.00 b	7.83 a,b	5.17 a	6.75 a,b	5.08 a	4.07 a
ODI[b]	14.21 a	30.29 b	19.89 a,b	9.46 a	13.77 a	7.62 a	7.20 a
No. Ps[c]							
Per Plant	6.17 a	9.92 a	9.08 a	9.08 a	7.33 a	7.50 a	8.27 a
Per Coffin-Holder	162.33 a	392.50 a,b	524.17 b,c	640.50 b,d	787.83 d	771.42 c,d	873.67 d
No. WH/Coffin-Holder	25.92 a	39.75 a	56.08 a	68.83 a	90.92 a	87.67 a	87.87 a
Ps Width (cm) (PsW)	7.39 a	5.44 a	5.27 a	4.43 a	4.39 a	4.05 a	3.77 a
Ps Length (cm) (PsL)	6.94 a	5.07 a	5.07 a	3.80 a	3.52 a	3.31 a	3.50 a
Petiole Length (cm) (PL)	10.78 a	7.05 a	7.25 a	5.15 a	5.01 a	4.60 a	6.25 a
Root Length (cm) (RL)	34.14 a	32.66 a	40.18 a	38.69 a	38.91 a	41.33 a	32.61 a

Table 28.— Continued.

Source	Septenary No.						
	1	2	3	4	5	6	7
WH Weight (g)							
Wet	149.70 a	101.86 a	90.87 a	105.62 a	127.91 a	108.90 a	91.39 a
Dry	-	-	-	-	-	-	4.69
PMF[d]	0.74 a	0.54 a	0.44 a	0.35 a	0.33 a	0.29 a	0.42 a

[a]NDI= [5 - (age of NE feeding spots)](no./cm^2).

[b]ODI= (age of OT tunnels)(no./cm^2).

[c]Ps= pseudolamina(e).

[d]PMF= $\left(\frac{PsW + PsL + PL}{RL}\right)$.

Table 29.— Septenarial averages of _Neochetina eichhorniae_ Warner (NE), _Orthogalumna terebrantis_ Wallwork (OT) and waterhyacinth (WH) parameters for uncovered control coffin-holders. Values are averages of 63 samples each. Values in the same row followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Source	Septenary No. 1	2	3	4	5	6	7
No. NE/Plant	0.00 a	0.00 a	0.44 b	0.22 a,b	0.00 a	0.11 a	0.22 a,b
NE Feeding Spots							
Age	1.41 a	2.29 a	2.60 a	2.68 a	3.25 a	1.85 a	1.18 a
No./cm^2	1.81 a	2.75 a	5.75 a	4.92 a	5.03 a	4.25 a	2.84 a
NDI[a]	6.50 a	7.45 a,b	13.80 c	11.41 a–c	8.80 a–c	13.39 b,c	10.85 a–c
No. OT/Plant	25.03 b	12.42 a,b	9.83 a,b	2.47 a,b	1.78 a	1.92 a,b	1.05 a
OT Tunnels							
Age	2.46 a	2.35 a	1.00 a	0.33 a	0.08 a	0.14 a	0.06 a
No./cm^2	9.56 c	7.20 b,c	1.47 a,b	0.64 a,b	0.44 a,b	0.17 a	0.31 a,b
ODI[b]	23.52 b	16.92 b	1.47 a	0.21 a	0.04 a	0.02 a	0.02 a
No. Ps[c]							
Per Plant	6.92 a	9.33 a	8.36 a	5.83 a	5.89 a	5.42 a	4.91 a
Per Coffin-Holder	199.79 a	399.95 a	301.70 a	233.47 a	265.72 a	252.55 a	183.61 a
No. WH/Coffin-Holder	28.71 a	35.23 a	33.61 a	32.75 a	34.91 a	32.58 a	26.11 a
Ps Width (cm) (PsW)	6.12 a	4.58 a	3.67 a	3.01 a	2.73 a	2.44 a	2.00 a
Ps Length (cm) (PsL)	5.81 a	4.09 a	3.71 a	2.74 a	2.43 a	2.08 a	1.81 a
Petiole Length (cm) (PL)	8.49 a	5.15 a	4.98 a	3.57 a	3.26 a	3.06 a	3.07 a
Root Length (cm) (RL)	30.62 a,b	29.12 a,b	27.67 a,b	28.37 a,b	32.23 b	25.36 a,b	19.90 a

Table 29.— Continued.

Source	Septenary No.						
	1	2	3	4	5	6	7
WH Weight (g)							
Wet	170.48 a	128.43 a	131.40 a	119.38 a	155.20 a	119.85 a	92.00 a
Dry	-	-	-	-	-	-	3.85
PMF[d]	0.67 a	0.47 a	0.45 a	0.33 a	0.26 a	0.30 a	0.35 a

[a] NDI= [5 - (age of NE feeding spots)] $(no./cm^2)$.

[b] ODI= (age of OT tunnels) $(no./cm^2)$.

[c] Ps= pseudolamina(e).

[d] PMF= $\left(\frac{PsW + PsL + PL}{Rl}\right)$.

Table 30.— Septenarial averages of Neochetina eichhorniae Warner (NE) and Orthogalumna terebrantis Wallwork (OT) populations and damage data for coffin-holder experiment. Values are averages of 21 samples each. Values in the same column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Treatment	Septenary	NE/ Plant	NE Feeding Spots: Age	NE Feeding Spots: No./cm^2	NE Feeding Spots: NDI[a]	OT/ Plant	OT Tunnels: Age	OT Tunnels: No./cm^2	OT Tunnels: ODI[b]
NE + OT	1	0.50 a	2.59 i-r	6.33 l-r	14.54 u-w	82.33 j	2.50 h-j	13.00 k	13.17 b-h
	2	0.08 a	3.30 o-t	6.92 o-r	8.75 j-s	9.75 a-d	2.25 f-j	5.50 e-i	14.33 c-i
	3	0.00 a	3.25 m-t	7.42 q-r	11.34 o-v	6.50 a-c	1.17 a-g	0.50 a-d	3.40 a-d
	4	0.08 a	3.13 k-t	5.17 j-q	10.46 n-u	0.50 a	0.29 a-c	0.50 a-d	1.74 a-d
	5	0.00 a	2.21 g-l	2.33 b-g	3.21 a-g	0.50 a	0.00 a	0.00 a	0.00 a
	6	0.00 a	3.28 p-t	6.83 n-r	10.71 n-u	2.33 a,b	0.08 a,b	0.33 a,b	0.33 a
	7	0.00 a	2.97 j-t	6.13 k-r	10.63 k-r	2.47 a,b	0.70 a-e	1.06 a-e	2.10 a-c
NE Alone	1	0.50 a	2.00 f-j	6.33 l-r	16.13 w	19.08 a-g	2.00 f-j	4.58 a-h	10.90 a-h
	2	0.00 a	2.30 h-n	7.33 p-r	10.96 o-u	3.00 a,b	1.21 a-h	2.83 a-g	9.58 a-g
	3	0.25 a	3.25 m-t	7.00 o-r	11.84 p-v	0.75 a	0.33 a-d	0.17 a	0.67 a,b
	4	0.00 a	3.17 l-t	5.58 k-q	8.38 i-r	0.83 a	0.29 a-c	0.50 a-d	0.88 a,b
	5	0.00 a	3.34 o-t	5.25 j-q	7.25 f-n	0.00 a	0.00 a	0.00 a	0.00 a
	6	0.25 a	2.46 i-q	5.92 k-q	14.13 t-w	0.00 a	0.00 a	0.00 a	0.00 a
	7	0.00 a	2.00 f-j	4.13 e-l	8.03 h-q	0.40 a	0.07 a	0.17 a	0.13 a
OT Alone	1	0.33 a	0.92 a-e	0.58 a-c	0.67 a-c	31.08 d-h	1.59 d-j	8.33 h-j	22.33 h-l
	2	0.00 a	2.96 j-s	3.17 d-j	4.83 c-k	17.42 a-f	3.75 k	9.50 i-k	37.17 m
	3	0.00 a	3.46 r-t	6.75 n-r	8.92 k-s	4.50 a,b	2.42 g-j	2.25 a-f	8.00 a-g
	4	0.00 a	3.29 n-t	6.83 n-r	10.08 l-t	3.25 a,b	0.29 a-c	0.33 a,b	1.10 a,b
	5	0.00 a	2.33 h-n	5.00 i-p	5.00 d-k	0.00 a	0.00 a	0.00 a	0.00 a
	6	0.08 a	2.17 g-k	3.83 d-k	5.21 d-k	1.42 a	0.08 a,b	0.58 a-d	0.58 a
	7	0.00 a	1.40 d-h	2.80 c-i	3.30 a-g	0.27 a-c	0.27 a-c	0.27 a	0.40 a
NE established 3 months, OT added	1	5.80 b	2.42 i-p	5.75 k-q	12.42 r-w	3.25 a,b	2.04 f-j	5.25 d-i	14.84 d-j
	2	0.08 a	3.96 t	9.83 s	10.21 m-t	29.00 c-h	2.58 i-k	3.83 a-h	14.42 d-i
	3	0.00 a	3.21 m-t	7.50 q-r	12.17 q-w	2.67 a,b	1.33 b-i	1.50 a-e	6.00 a-f
	4	0.00 a	3.55 r-t	7.33 p-r	11.05 o-u	0.67 a	0.29 a-c	0.17 a	0.58 a
	5	0.00 a	3.50 r-t	5.33 j-q	5.92 f-l	0.00 a	0.00 a	0.00 a	0.00 a

Table 30.— Continued.

Treatment	Septe-nary	NE/ Plant	NE Feeding Spots			OT/ Plant	OT Tunnels		
			Age	No./cm^2	NDI[a]		Age	No./cm^2	ODI[b]
	6	0.00 a	3.25 m-t	6.67 n-r	10.63 n-u	4.00 a,b	0.08 a,b	0.33 a,b	0.33 a
	7	0.00 a	2.79 i-n	6.53 m-r	13.51 t-w	0.40 a	0.00 a	0.00 a	0.00 a
OT established 3 months, OT added	1	0.08 a	0.54 a-d	0.75 a-c	1.63 a-e	55.50 i	2.25 f-j	10.33 j,k	26.63 j-m
	2	0.08 a	2.38 h-o	5.00 i-p	12.54 r-w	31.42 d-h	2.71 j,k	10.92 j,k	29.65 k-m
	3	0.00 a	3.13 k-t	8.25 r,s	15.46 v,w	30.08 d-h	1.83 e-j	2.17 a-f	8.17 a-g
	4	0.00 a	3.79 s,t	7.25 o-r	8.50 i-r	6.17 a-c	0.25 a-c	0.42 a-c	1.25 a,b
	5	0.08 a	3.41 q-t	5.92 k-q	7.63 h-p	1.08 a	0.17 a,b	0.67 a-d	0.67 k-q
	6	0.67 a	2.17 g-k	5.67 k-q	12.96 s-w	20.67 a-g	0.67 a-e	0.75 a-d	3.00 a-d
	7	0.40 a	1.87 e-i	4.53 g-n	6.43 f-n	11.67 a-e	0.43 a-d	1.00 a-e	1.33 a,b
Covered Controls	1	0.00 a	1.41 d-h	1.81 a-d	4.19 b-i	25.03 b-h	2.46 g-j	9.56 i-k	25.39 i-l
	2	0.00 a	2.29 h-m	2.75 c-i	4.22 b-i	12.42 a-e	2.35 g-j	7.20 g-j	19.98 g-l
	3	0.44 a	2.60 i-r	5.75 k-q	11.26 o-v	9.83 a-d	1.00 a-f	1.47 a-e	5.22 a-e
	4	0.22 a	2.68 i-r	4.92 h-o	7.55 g-p	2.47 g-p	0.33 a-d	0.64 a-d	1.47 a,b
	5	0.00 a	3.25 m-t	5.03 i-p	6.07 f-m	1.78 a,b	0.08 a,b	0.44 a-c	0.25 a
	6	0.11 a	1.85 e-i	4.25 f-m	7.99 h-q	1.92 a,b	0.14 a,b	0.17 a	0.50 a
	7	0.22 a	1.18 a-f	2.84 c-i	5.40 e-k	1.05 a	0.06 a,b	0.31 a	0.31 a
Uncovered Controls	1	0.00 a	0.33 a,b	0.42 a,b	0.42 a,b	8.58 a-d	1.96 e-j	7.25 g-j	18.00 f-k
	2	0.00 a	0.38 a-c	0.42 a,b	1.08 a-d	46.33 h,i	2.33 g-j	13.00 k	30.34 l,m
	3	0.00 a	0.00 a	0.00 a	0.00 a	41.42 g-i	2.54 i,j	7.83 h-j	25.83 i-m
	4	0.00 a	1.42 d-h	2.00 a-f	3.08 a-f	89.67 j	1.83 e-j	5.17 c-i	17.25 e-j
	5	0.00 a	1.33 c-g	1.92 a-e	3.75 a-h	28.17 c-h	2.04 f-j	6.75 f-j	22.46 h-l
	6	0.00 a	1.29 c-g	2.68 c-h	4.50 b-j	39.42 f-i	1.50 c-j	5.08 b-i	11.63 a-h
	7	0.00 a	2.30 h-n	5.20 j-q	8.40 i-r	33.60 e-h	1.77 e-j	4.07 a-h	11.17 a-h

[a] NDI= $[5 - (\text{age of NE feeding spots})](\text{no./cm}^2)$.

[b] ODI= $(\text{age of OT tunnels})(\text{no./cm}^2)$.

Table 31.— Septenarial averages of waterhyacinth measurements for coffin-holder experiment. Values are averages of 21 samples each. Values in the same column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Treatment	Septenary	Ps[a]/ Plant	Plants/ Coffin-Holder	Ps Width (PsW) (cm)	Ps Length (PsL) (cm)	Petiole Length (PL) (cm)	Root Length (RL) (cm)	Plant Wet Weight (g)	PMF[b]
NE[c] + OT[d]	1	6.17 c-i	23.58 a-l	7.35 o	6.69 l	8.99 i-l	27.48 k,l	191.85 r	0.84 n
	2	8.42 l-p	26.42 d-m	5.08 i-m	4.30 h-k	6.56 e-i	21.02 c-j	131.89 h-o	0.76 l-n
	3	8.42 l-p	23.83 b-l	4.49 g-l	4.03 e-j	5.67 b-h	23.30 e-m	137.87 i-p	0.61 f-m
	4	5.58 a-f	20.13 b-j	3.95 c-j	3.95 c-j	4.48 a-g	20.76 c-i	102.50 a-h	0.57 e-l
	5	5.33 a-e	15.33 a-h	2.73 a-h	2.41 a-h	3.14 a-c	23.96 e-o	120.64 d-m	0.36 a-e
	6	5.50 a-f	11.83 a-f	2.25 a-d	2.02 a-d	2.79 a,b	22.24 e-l	102.52 a-h	0.32 a-d
	7	6.63 c-j	7.60 a-c	2.41 a-f	2.01 a-d	3.05 a-c	15.73 a-c	101.21 a-h	0.48 b-i
NE Alone	1	6.50 d-j	21.25 b-j	6.60 m-o	5.97 k,l	11.62 l	30.76 p-t	161.67 o-r	0.79 m,n
	2	8.25 k-o	24.25 c-l	4.29 e-k	3.65 c-i	4.70 a-g	24.86 f-p	104.57 b-j	0.51 c-j
	3	8.33 l-p	21.83 b-k	3.70 a-j	3.40 a-i	4.70 a-g	23.29 e-n	111.61 c-l	0.51 c-j
	4	6.83 e-l	15.75 a-i	2.91 a-h	2.51 a-h	3.37 a-d	20.92 c-j	94.67 a-f	0.42 a-g
	5	6.00 b-i	13.25 a-g	2.55 a-h	2.36 a-h	3.30 a-d	21.79 c-k	104.00 b-i	0.38 a-e
	6	5.00 a-d	11.17 a-e	2.14 a-d	1.84 a-c	2.61 a	20.33 b-h	87.10 a-d	0.32 a-d
	7	4.67 a-c	7.20 a-c	1.74 a	1.63 a,b	2.34 a	14.45 a,b	68.18 a	0.40 a-f
OT Alone	1	7.08 f-m	24.17 c-l	7.11 n-o	6.18 l	9.00 i-l	27.13 j-r	144.78 k-p	0.82 m,n
	2	8.42 l-p	30.58 g-m	4.28 e-k	3.94 d-j	5.17 a-g	28.67 m-s	117.66 c-m	0.47 b-i
	3	6.92 e-m	26.50 d-m	3.46 a-j	3.64 c-i	4.62 a-g	22.56 e-m	93.25 a-e	0.52 c-j
	4	5.58 a-f	21.33 b-j	2.59 a-h	2.63 a-h	3.38 a-d	25.25 g-q	118.21 c-m	0.34 a-d
	5	5.17 a-e	14.58 a-g	2.39 a-f	2.11 a-f	2.62 a	21.19 q-t	118.88 c-m	0.23 a
	6	4.42 a,b	6.67 a,b	1.92 a-c	1.62 a	2.20 a	20.95 c-j	76.47 a,b	0.27 a,b
	7	4.00 a	2.87 a	1.81 a,b	1.62 a	2.31 a	13.63 a	102.85 a-h	0.42 a-g
NE established 3 months, OT added	1	5.50 a-f	21.67 b-k	6.34 l-o	6.23 l	7.30 g-j	31.78 r-t	139.12 a-h	0.63 g-n
	2	7.92 j-o	26.83 e-m	3.87 b-j	3.67 c-i	4.95 a-g	19.02 a-g	97.43 a-h	0.66 h-n
	3	7.33 g-m	22.50 b-l	3.14 a-i	3.21 a-i	5.10 a-g	15.82 a-d	97.28 a-h	0.72 j-n
	4	5.92 b-h	15.08 a-g	2.79 a-h	2.73 a-h	3.68 a-e	17.96 a-e	96.93 a-g	0.51 c-j

Table 31.— Continued.

Treatment	Septenary	Ps[a]/ Plant	Plants/ Coffin-Holder	Ps Width (PsW) (cm)	Ps Length (PsL) (cm)	Petiole Length (PL) (cm)	Root Length (RL) (cm)	Plant Wet Weight (g)	PMF[b]
	5	6.50 d-j	11.00 a-e	2.59 a-h	2.31 a-g	3.18 a-c	18.74 a-f	103.29 b-i	0.43 a-g
	6	5.75 b-g	9.17 a-d	2.02 a-d	1.85 a-c	2.62 a	17.68 a-e	95.19 a-f	0.37 a-e
	7	6.00 b-i	8.10 a-c	2.18 a-d	1.98 a-d	2.96 a-c	18.93 a-f	90.28 a-d	0.38 a-e
OT established 3 months, NE added	1	7.00 f-m	28.58 f-m	7.09 n,o	6.97 l	10.03 j-l	29.00 n-s	184.59 q,r	0.83 n
	2	8.58 m-p	38.75 k-n	4.46 f-l	4.25 g-k	5.16 a-g	32.48 r-t	110.78 b-k	0.43 a-g
	3	8.25 k-o	43.50 m-o	3.79 a-j	3.62 b-i	5.96 c-h	35.36 t-v	150.37 m-p	0.38 a-e
	4	6.83 e-l	50.33 n-o	3.62 a-j	3.08 a-i	4.30 a-g	26.88 i-r	121.18 d-n	0.41 a-f
	5	7.67 i-o	71.17 p	3.20 a-i	2.76 a-h	3.68 a-e	39.97 v,w	145.92 l-p	0.24 a
	6	6.25 c-j	71.67 p	3.04 a-i	2.42 a-h	4.24 a-f	30.01 o-t	94.30 a-f	0.32 a-d
	7	6.60 d-k	69.00 p	2.81 a-h	2.41 a-h	5.04 a-g	22.04 d-k	85.64 a-c	0.47 b-i
Covered Controls	1	6.92 e-m	28.71 f-m	6.12 k-o	5.81 j-l	8.49 h-j	30.62 p-t	170.48 p-r	0.67 i-n
	2	9.33 o,p	35.25 j-n	4.58 h-l	4.09 f-j	5.15 a-g	29.12 n-s	128.43 f-o	0.47 b-i
	3	8.36 l-p	33.61 j-m	3.67 a-j	3.73 c-i	4.98 a-g	27.67 k-r	131.40 g-o	0.45 a-h
	4	5.83 b-h	32.75 i-m	3.01 a-i	2.74 a-h	3.57 a-e	28.37 l-s	119.38 c-m	0.33 a-d
	5	5.89 b-h	34.91 j-m	2.73 a-h	2.43 a-h	3.26 a-d	32.23 r-t	155.20 n-q	0.26 a,b
	6	5.42 a-f	32.58 h-m	2.44 a-g	2.08 a-e	3.06 a-c	25.36 h-q	119.85 c-m	0.30 a-c
	7	4.91 a-c	26.11 d-l	2.00 a-d	1.81 a-c	3.07 a-c	19.90 b-h	92.00 a-d	0.35 a-e
Uncovered Controls	1	6.17 c-i	25.92 d-l	7.39 o	6.94 l	10.78 k,l	34.14 s-u	149.70 m-p	0.74 k-n
	2	9.92 p	39.75 l-n	5.44 j-o	5.07 i-l	7.05 f-i	32.66 r-t	101.86 a-h	0.54 d-k
	3	9.08 n-p	56.08 o,p	5.27 j-n	5.07 i-l	7.25 f-j	40.18 v,w	90.87 a-d	0.44 a-g
	4	9.08 n-p	68.83 p	4.43 f-l	3.80 c-i	5.15 a-g	38.69 u-w	105.62 b-j	0.35 a-e
	5	7.33 g-m	90.92 q	4.39 f-l	3.52 a-i	5.00 a-g	38.90 u-w	127.90 e-o	0.33 a-d
	6	7.50 h-n	87.67 q	4.05 d-j	3.30 a-i	4.60 a-g	41.33 w	108.90 b-j	0.29 a,b
	7	8.27 k-o	87.87 q	3.77 a-j	3.50 a-i	6.25 d-i	32.61 r-t	91.39 a-d	0.41 a-f

[a]Ps= pseudolamina(e).

[b]PMF= $\frac{(PsW + PsL + PL)}{RL}$.

[c]NE= Neochetina eichhorniae Warner.

[d]OT= Orthogalumna terebrantis Wallwork.

Table 32.— Population parameters of *Neochetina eichhorniae* Warner (NE) and *Orthogalumna terebrantis* Wallwork (OT) grown in incubators. Temperature regimes for incubators 1–4 were (°C): 5–25, 10–30, 15–35 and 20–40, respectively. Values in the same column followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Incubator No.	OT	No. OT/Ps[a] Total	No. OT/Ps[a] Avg./wk	No. Dead NE Total	No. Dead NE Avg./wk	No. NE Eggs Total	No. NE Eggs Avg. OT/wk	No. NE Feeding Spots Total	No. NE Feeding Spots Avg./NE/wk	No. OT Tunnels Total	No. OT Tunnels Avg./OT/wk
1–	0	0 a	0.0 a	12 e	6.0 g	0 a	0.0 a	2 a	0.1 a	0 a	0.00 a
	50	89 b,c	44.5 d	12 e	6.0 g	0 a	0.0 a	13 a	0.2 a	0 a	0.00 a
	100	139 c,d	69.5 e	12 e	6.0 g	0 a	0.0 a	2 a	0.1 a	0 a	0.00 a
	150	167 d-f	83.5 e	12 e	6.0 g	0 a	0.0 a	21 a	0.4 a	0 a	0.00 a
	200	245 g,h	122.5 f	12 e	6.0 g	0 a	0.0 a	20 a	0.3 a	0 a	0.00 a
2–	0	0 a	0.0 a	0 a	0.0 a	2 a	0.1 a	3859 f,g	64.3 f,g	0 a	0.00 a
	50	93 b,c	9.3 a,b	8 c–e	0.8 c,d	6 a,b	0.2 a–c	3511 e,f	58.5 e,f	147 b–d	0.29 h
	100	212 e–g	21.2 a–d	8 c–e	0.8 c,d	20 c,d	0.7 d	3925 f–h	65.4 f–h	170 c–f	0.17 c–g
	150	225 f–g	22.5 a–d	7 c,d	0.7 c,d	16 b–d	0.5 c,d	3927 f–h	65.4 f–h	339 g,h	0.23 g,h
	200	293 h	29.3 b–d	7 c,d	0.7 c,d	19 c,d	0.6 d	3905 f–h	65.1 f–h	405 h	0.20 e–g
3–	0	0 a	0.0 a	1 a,b	0.1 a,b	33 e	1.1 e	4068 g,h	67.8 g,h	0 a	0.00 a
	50	77 b	7.7 a,b	5 b–d	0.5 b–d	36 f	1.2 e	4319 h	72.0 h	107 a–d	0.21 f,g
	100	134 b–d	13.4 a–c	6 c,d	0.6 c,d	13 a–c	0.4 b–d	4142 g,h	69.0 g,h	154 b–e	0.15 c–f
	150	233 g	23.3 a–d	4 a–c	0.4 a–c	24 d,e	0.8 d,e	4067 g,h	67.8 g,h	271 f,g	0.18 d–g
	200	396 i	39.6 c,d	5 b–d	0.5 b–d	19 c,d	0.6 d	3240 d,e	54.0 d,e	199 d–f	0.10 b,c
4–	0	0 a	0.0 a	9 d,e	0.9 d	3 a	0.1 a,b	3039 c,d	50.6 c,d	0 a	0.00 a
	50	92 b,c	9.2 a,b	26 g	2.6 f	0 a	0.0 a	2733 b,c	45.6 b,c	85 a–c	0.17 c–g
	100	156 d,e	15.6 a–c	25 g	2.5 f	0 a	0.0 a	2408 b	40.1 b	59 a,b	0.06 a,b
	150	168 d–f	16.8 a–c	20 f	2.0 e	0 a	0.0 a	3252 d,e	54.2 d,e	175 c–f	0.12 b–d
	200	222 f,g	22.2 a–d	20 f	2.0 e	1 a	0.1 a	2717 b,c	45.3 b,c	260 e–g	0.13 c–e

[a]Ps= pseudolamina

Table 33.— Oviposition and development of <u>Orthogalumna terebrantis</u> Wallwork (OT) at 4 different temperature regimes. Field-collected waterhyacinth pseudolaminae bearing tunnels containing deuto- or tritonymphs of OT were provided to obtain development to adult data.

Source	Temperature Regimes (°C)			
	5-25	10-30	15-35	20-40
No. OT Eggs Laid				
Total	6.00	529.00	598.00	599.00
Per Female	0.24	51.16	23.92	23.96
OT Tunnels				
Total Provided	625.00	3237.00	3083.00	1890.00
Total Adults Emerged	26.00	1398.00	704.00	348.00
% Emerged	4.20	43.20	22.80	18.40

Table 34.— Water quality measurements at release site of Neochetina eichhorniae Warner taken 50 weeks after release. Values in the same row followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Test	Open Water To lt. of mat	Open Water To rt. of mat	Under mat
Total Alkalinity (ppm)	244.0 a	246.0 b	248.0 c
Hydroxide " "	0.0 a	0.0 a	0.0 a
Carbonate " "	0.0 a	0.0 a	0.0 a
NaCl (ppm)	200.0 b	200.0 b	150.0 a
$CaCO_3$ (ppm)	160.0 c	158.0 b	92.0 a
Color	350.0 b	300.0 a	300.0 a
Cu (ppm)	0.0 a	0.0 a	0.0 a
$MgCO_3$ (ppm)	10.0 b	12.0 c	8.0 a
Total Hardness (ppm)	170.0 c	160.0 b	100.0 a
NO_3 (ppm)	0.001 a	0.0 a	0.0 a
pH	7.15 a	7.62 c	7.2 b
Total PO_4 (ppm)	0.15 b	0.15 b	0.12 a
Available PO_4 (ppm)	0.08 b	0.08 b	0.05 a
Turbidity (JTU)	1.25 b	1.20 a	1.40 c

Table 35.— Water quality measurements from concrete coffin-holders and pondwater at USDA Aquatic Plant Management Laboratory, Davie, Florida. All measurements are averages of 3 replicates each except pondwater, which represents an average of 72 samples from July 1974 to July 1975. Values in the same row followed by the same letter are not significantly different at the 5% level as determined by Duncan's Multiple Range Test.

Test	From Coffin-Holders Containing							Pond-water
	NE[a] Alone	OT[b] Alone	NE + OT	NE, Delay	OT, Delay	Control, Uncovered	Control, Covered	
Total Alkalinity (ppm)	48.0 b	42.0 a	42.0 a	42.0 a	98.0 e	50.0 c	126.0 f	56.95 d
Hydroxide " "	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	1.08 b
Carbonate " "	4.0 c	4.0 c	4.0 c	5.0 d	0.0 a	2.0 b	0.0 a	--.--
NaCl (ppm)	100.0 a	100.0 a	100.0 a	100.0 a	100.0 a	100.0 a	100.0 a	--.--
$CaCO_3$ (ppm)	76.0 e	68.0 c	68.0 c	62.0 b	122.0 f	73.3 d	146.0 g	59.80 a
Color	25.0 b	22.0 a	40.0 f	25.0 b	37.0 e	27.3 c	45.0 g	29.25 d
Cu (ppm)	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	--.--
$MgCO_3$ (ppm)	8.0 b	14.0 e	10.0 c	12.0 d	14.0 e	19.3 f	6.0 a	29.00 g
Total Hardness (ppm)	84.0 e	82.0 d	78.0 b	74.0 a	136.0 g	92.8 f	152.0 h	79.15 c
NO_3 (ppm)	0.02 b	0.01 a	0.06 e	0.01 a	0.04 c	0.02 b	0.04 d	--.--
pH	8.9 e	9.0 e	9.0 e	9.0 e	7.5 b	8.6 d	7.2 a	8.35 c
Total PO_4 (ppm)	0.01 a	0.01 a	0.10 c	0.01 a	0.03 b	0.01 a	0.04 b	0.01 a
Available PO_4 (ppm)	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a
Turbidity (JTU)	1.7 c	1.7 c	4.4 g	2.2 e	2.3 f	1.2 b	1.8 d	1.04 a

[a]NE= Neochetina eichhorniae Warner (Coleoptera: Curculionidae).

[b]OT= Orthogalumna terebrantis Wallwork (Acari: Galumnidae).

Table 36.— Amount of N, P, K and crude protein (CP) from waterhyacinth samples.

Source		%N	P(ppt)	K(ppm)	%CP
Canal- Area	1	1.6026	2.1518	47.04	10.0167
	2	1.9174	3.0909	99.33	11.9839
	3	1.5454	2.0606	94.24	9.6587
	4	1.5168	2.1212	95.86	9.4798
	5	1.3021	1.4546	85.63	8.1383
	6	1.0732	1.0909	62.84	6.7074
	7	1.3738	2.0606	86.31	10.6424
	8	1.6169	1.5151	67.52	8.5855
	9	1.6169	1.9394	51.24	10.1058
	10	1.8459	3.8182	59.06	11.5368
	Avg.	1.5497	2.1333	74.91	9.6855
Coffin-Holders					
NE[a] + OT[b]- Rep.	1	1.2306	0.5212	2.68	7.6912
	2	1.2574	0.5091	4.61	7.8585
	3	1.5384	1.8182	16.31	9.6151
	Avg.	1.3421	0.9495	7.87	8.3883
NE Alone	1	0.8728	0.3758	4.40	5.4547
	2	0.7248	0.8485	7.38	4.5302
	3	1.1612	0.5091	5.84	7.2575
	Avg.	0.9196	0.1926	5.87	5.7475
OT Alone	1	1.1734	0.5212	2.92	7.3334
	2	1.3091	0.4849	5.64	8.1820
	3	1.1390	0.6303	3.98	7.1188
	Avg.	1.2072	0.5455	4.18	7.5447
NE established 3 months, OT added	1	1.1464	0.5455	5.01	7.1651
	2	1.3831	0.6667	8.07	8.6443
	3	1.0207	0.9091	3.82	6.3792
	Avg.	1.1834	0.7071	5.63	7.3962
OT established 3 months, NE added	1	1.1094	0.7636	8.06	6.9339
	2	1.1390	0.6061	4.67	7.1188
	3	1.4792	2.0606	13.33	9.2453
	Avg.	1.2425	1.1434	8.69	7.7660
Covered Controls	1	0.9630	0.5818	6.76	6.1019
	2	0.8062	0.5818	24.49	5.0387
	3	1.1760	2.7273	10.06	7.3500
	Avg.	0.9817	1.2970	13.37	6.1635

Table 36.— Continued.

Source		%N	P(ppt)	K(ppm)	%CP
Uncovered Controls	1	1.0823	0.5414	4.46	6.1019
	2	1.3338	0.6707	9.17	8.3361
	3	1.2771	0.8000	5.85	7.9817
	Avg.	1.2311	0.6707	6.49	7.6941

[a]NE= Neochetina eichhorniae Warner (Coleoptera: Curculionidae).

[b]OT= Orthogalumna terebrantis Wallwork (Acari: Galumnidae).

Table 37.— Elemental content of waterhyacinth from various sources.

%Dry Weight Basis							ppm Dry Wt. Basis				
Ca	P	N	K	Mg	Na	Crude Protein	Fe	Cu	Zn	Mn	Source
2.20	0.50	-.--	4.10	0.50	0.94	-.--	1701	12	43	142	Easley and Shirley 1974
-.--	-.--	-.--	-.--	-.--	-.--	1.10	----	--	--	---	Boyd 1968a
-.--	0.40	4.00	0.00	0.00	0.00	0.00	----	--	---	---	Steward 1969
1.35	0.54	2.39	4.45	0.55	0.41	-.--	3240	15	67	270	Boyd 1971b
1.00	4.40	2.50	4.40	1.00	0.00	0.90	----	--	---	---	Boyd 1969
2.57	0.46	1.43	2.64	0.62	-.--	-.--	----	--	--	---	Knipling et al. 1970
1.00	0.43	2.64	4.25	1.05	0.34	-.--	250	--	50	3940	Boyd 1970
-.--	-.--	2.05	-.--	-.--	-.--	-.--	----	--	--	----	Basak 1948

Table 38.— Temperature (^{o}C) and dissolved oxygen (DO)(ppm) readings from release canal and coffin-holders, Davie, Florida, May, 1975. *Neochetina eichhorniae* Warner (NE) and *Orthogalumna terebrantis* Wallwork (OT) were added to waterhyacinth in coffin-holders in May 1974.

Source	Surface		Bottom	
	Temperature	DO	Temperature	DO
Canal- Area 1	26.0	3.8	25.9	0.6
2	26.0	0.8	25.9	0.3
3	26.0	1.2	25.9	0.6
4	26.0	1.6	25.9	0.7
5	25.8	1.0	25.8	0.4
6	25.9	0.6	25.9	0.3
7	25.9	0.7	25.9	0.4
8	25.9	1.7	25.8	0.9
9	26.0	0.8	25.9	0.2
10	25.8	0.7	25.8	0.6
Avg.	25.9	1.3	25.9	0.5
Open Water East of Area 1	26.0	0.2	25.9	0.3
Open Water West of Area 10	26.0	1.9	24.9	0.9
Avg.	26.0	1.1	25.4	0.6
Coffin-Holders- NE + OT	27.7	8.3	27.0	6.3
NE Alone	27.5	7.3	26.7	5.5
OT Alone	28.1	6.5	27.8	5.3
NE established 3 months, OT added	27.5	6.7	27.2	5.3
OT established 3 months, NE added	27.6	5.8	27.3	3.9
Covered Controls	27.0	6.7	26.5	4.8
Uncovered Controls	27.8	5.7	27.3	4.3
Avg.	27.6	6.7	27.1	5.1

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BIOGRAPHICAL SKETCH

Ernest Sheridan Del Fosse was born 26 April 1949 in Glen Ridge, New Jersey. He attended Cedar Grove, New Jersey, Public Schools until 1967, when he graduated from Cedar Grove Memorial High School. He was employed at Doremus Animal Hospital in Cedar Grove from 1961 to 1967. In 1967 he enrolled in the School of Arts and Sciences at the University of Louisville, Louisville, Kentucky, where he received the Bachelor of Science degree in zoology in 1971. From 1970 to 1971 he worked as the Curator of Louisville's Collection of Amphibians and Reptiles.

He entered South Dakota State University with a Research Assistantship in Entomology in 1971, where he received the Master of Science degree in entomology in 1972.

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Ernest S. Del Fosse is married to the former Janet Ann Veronica Fadayko, and they are childless.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree Doctor of Philosophy.

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